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What is the Sun made of? p. 30

December 2010

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How stars form

Stars change from cold gas to blazing hot fireballs — here's how they do it p. 26

See the nearest stars p. 52

How 5 doomed missions triumphed in the end p. 44

The Orion Nebula (M42) ranks among the biggest and brightest stellar nurseries in our galaxy. In this photo, luminous gas hides most of the thousands of newborn stars.

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- PlaneWave's hot new imaging scope p. 56
- *Astronomy*'s experts answer your questions p. 50

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This beautiful image of the Helix nebula was taken with an SBIG self-guiding STL-4020CM single-shot color camera by amateur imager Ed Henry through a 6" refractor.

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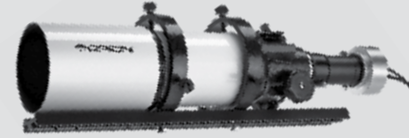

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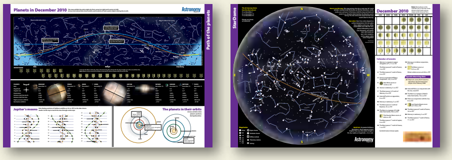

Path of the planets and StarDome.

Cover: Canada-France-Hawaii Telescope & Coelum - J.-C. Cuillandre (CFHT) & G. Anselmi (Coelum)

ON THE COVER

Scientists are combining more advanced simulations with observations to piece together how stars form. They're getting closer to solving this puzzle.

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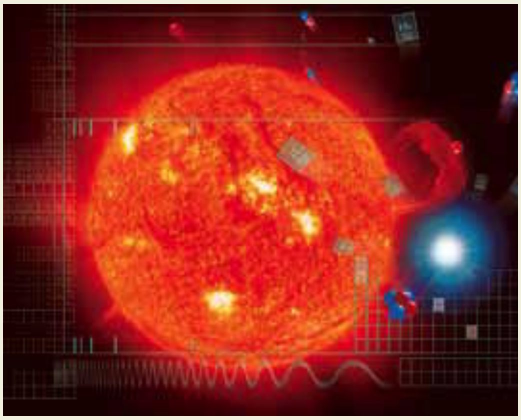
How stars form

Stars begin as clouds of cold gas that transform into blazing hot fireballs. Here's what scientists know about the process — and what they're missing. **LIZ KRUESI**



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By analyzing the Sun's light, astronomers are learning about not only our star's makeup, but also the early solar system. **JIM KALER**

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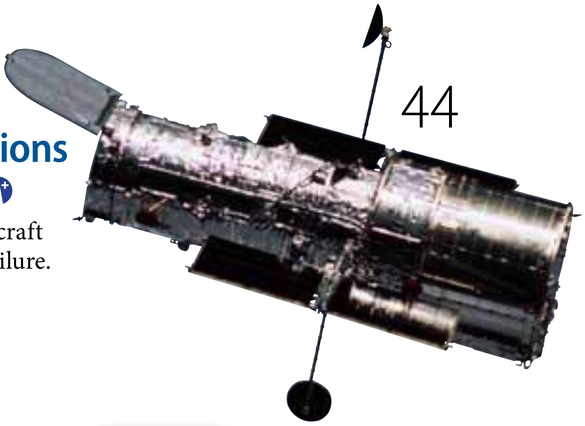
Venus blazes before dawn.

MARTIN RATCLIFFE AND ALISTER LING



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Like the mythic Phoenix, these spacecraft rose from the ashes of near-certain failure.

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Giant planets bruise, too.

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The stars next door are fun to hunt, easy to spot, and can teach you about astrophysics. **TEXT BY MICHAEL E. BAKICH; IMAGES BY ANTHONY AYIOMAMITIS**

56 PlaneWave's hot new astroimaging scope

The new CDK17 telescope offers thermal stability, ease of use, and killer images.

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BONUS!

Astronomy magazine's Sky Guide 2011

Bright planets, streaking meteors, and total eclipses of the Moon highlight an exceptional observing year. **MARTIN RATCLIFFE AND RICHARD TALCOTT**

WEB EXTRA

Visit **Astronomy.com/toc** for bonus material — it's exclusive to *Astronomy* magazine subscribers.

Astronomy (ISSN 0091-6358, USPS 531-350) is published monthly by Kalmbach Publishing Co., 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Periodicals postage paid at Waukesha, WI, and additional offices. POSTMASTER: Send address changes to *Astronomy*, 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Canada Publication Mail Agreement # 40010760.

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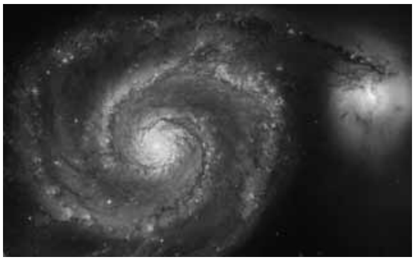

The Whirlpool Galaxy, as seen by the Hubble Space Telescope, is about 25 million light-years away from us.

NASA, ESA, S. Beckwith (STScI), and The Hubble Heritage Team (STScI/AURA).

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A natural teacher with a Ph.D. in astrophysics from Columbia University, Dr. Neil deGrasse Tyson has written prolifically for the public, including the series of essays in *Natural History* magazine on which this course is based. And though it was created for a lay audience and is readily accessible, the course is one in which science always takes precedence over drama.

It is certainly entertaining, often funny, even awe-inspiring at times, as befits the subject matter. But clear introductions to essential principles of physics abound throughout these lectures, including density, quantum theory, gravity, and even the General Theory of Relativity. And Dr. Tyson also includes forays into disciplines such as chemistry and biology as needed to explain events.

For example, Dr. Tyson begins one lecture at a point 13 billion years ago, when all space, matter, and energy in the known universe was contained in a volume less than one-trillionth the size of a pinpoint—about the size of an atom. By the time he finishes, the cosmos has been stretched, the planets and Earth formed, and 70 percent of Earth species wiped out by a gigantic asteroid—clearing the way for the evolution of humanity.

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This Month in *Astronomy*

Astronomy and *Discover* now sister magazines

by David J. Eicher

I'm pleased to let you know that Kalmbach Publishing Co., *Astronomy*'s publisher, has acquired Discover Media, including *Discover*, the world's leading popular magazine about science and technology. The acquisition makes our company one of the world's premier publishers of science journalism.

SPECIAL ANNIVERSARY ISSUE
DISCOVER
30
1980 2010
THIRTY YEARS THAT CHANGED EVERYTHING

DISCOVER magazine

Many of you are undoubtedly familiar with *Discover*, and you probably subscribe to it or at least buy it from time to time on the newsstand. Launched in 1980, *Discover* is published 10 times per year and covers a wide range of topics, including astronomy and space exploration, physics, the brain, medicine, biology and evolution, and energy and the environment. The magazine also produces four newsstand special editions each year.

Discover has a circulation of 700,000 and is one of the top-selling magazines at airport newsstands and other transportation hubs worldwide. Its editor, Corey S. Powell, is a lifelong reader of *Astronomy* magazine who does a terrific job of leading the ship at *Discover*, and I'm sure you'll see some future cooperative ventures between the titles. The magazine maintains a large, user-friendly website, DiscoverMagazine.com, featuring a deep well of science-related material, including daily news coverage, a popular lineup of bloggers, a variety of image galleries, and a large selection of video content.

Discover's staff covers the sciences in a superb way. "The hallmark of *Discover*'s editorial and design team is their ability to make complex subjects both entertaining and understandable," says Kevin Keefe, publisher of *Astronomy* and now *Discover*. "We will certainly continue *Discover*'s dedication to offering our readers compelling writing, exciting design, and great photography."

"We've taken another strategic step with *Discover*, a magazine with a solid editorial tradition," says Gerald Boettcher, president of Kalmbach. "With *Discover* and *Astronomy*, we strengthen our leadership position in publishing for the science category."

I'm sure many exciting things will come from this affiliation in the future. I will be delighted to share them with you as events unfold. In the meantime, keep looking up, and enjoy two of the finest magazines in the world.

Yours truly,

David J. Eicher
Editor

Astronomy

Volume 38, Number 12

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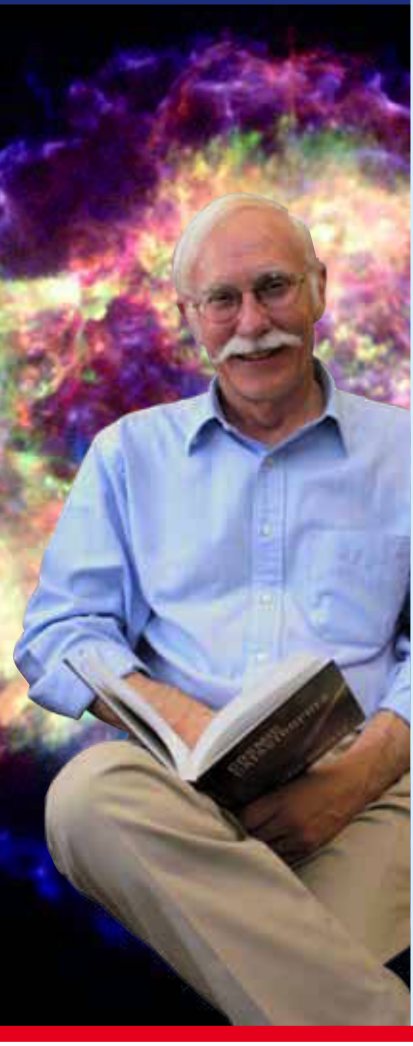
by Karri Ferron

OUR TURN



Mario Cervantes; Cassiopeia A: NASA/CXC/MIT/UMass Amherst/M.D. Stage, et al.

J. Craig **Wheeler**

Professor of astronomy at the University of Texas at Austin and author of *The Krone Experiment*

What made you decide to focus your research on supernovae?

First is the notion that supernovae are connected to everything else in the universe: the origin of elements and hence life, the birth of new stars, and the evolution of galaxies. These dimly defined ideas were "in the air" when I began. Second, I was especially interested in collapsed objects — neutron stars and black holes. Supernovae are a route to form them.

What are some exciting things you've learned through your research?

Supernova 1987A, the gamma-ray burst/supernova connection, and the supernova/dark energy connection were all revolutions. More technically, we are homing in on the mechanism of thermonuclear explosions in white dwarfs — a mix of subsonic and supersonic burning — a problem I have wrestled with my whole career. Finding out that core collapse supernovae — the type that make neutron stars and maybe black holes — are distinctly "out of round" and pondering the reasons for that truth has been both exciting and challenging.

What studies in astronomy do you find fascinating?

Two great quests that overlap with my research are understanding the nature of dark energy and the origin and nature of cosmic gamma-ray bursts. These are topics of huge importance, ranging from stellar astrophysics to the most fundamental questions of the origin and fate of the universe. The whole realm of exoplanet study (in which I do not actively work) and the more general area of astrobiology (in which I have dabbled) are deeply fascinating as well.

Why did you decide to write *The Krone Experiment*?

As a Massachusetts Institute of Technology undergraduate, I knew I was somewhat weird compared to my science- and engineering-oriented colleagues because I enjoyed my humanities and literature courses. I found that I love to write.

Today, I enjoy the process of trying to "tell the story" in my classes, research papers, and even grant proposals. More specifically, I was listening to a colloquium when the idea for *The Krone Experiment* (Onyx, 1988) popped into my head — a group of scientific intelligence experts tracking down the source of a mysterious seismic signal that is causing pinpoints of destruction around the globe. I wrote the first and last paragraphs that evening and then spent more than a decade filling in the missing bits. Turning it into a film was yet another adventure.

Astro**influences** *How did you become involved in promoting astronomy outreach?*

It really began while I was an undergraduate astronomy and physics major at the University of Minnesota, Twin Cities. I was one of many undergrads tapped to be a teaching assistant for the introductory astronomy labs. Among our various duties was the requirement to man the telescopes for our Friday night viewings. At first, I was a little intimidated, but then I discovered that it was one of my favorite things to do. Time would pass so quickly, and I would interact with people of all ages, plus I wouldn't notice the cold at all! Building on such feelings, I soon became outreach co-director for the Society of Physics Students.

When I moved on to graduate school at Georgia State University in Atlanta, I found a tradition of engaging the public there, too, and became an outreach leader. Fortunately, my Ph.D. advisor, Doug Gies, was extraordinarily supportive of all of my non-star-research activities, such as teaching, outreach, and education research. I have to thank him for encouraging me so much.

For my joint star-science/education-science postdoc, I went to Vanderbilt University in Nashville, Tennessee, and my outreach background has now led to interesting opportunities. Vanderbilt encourages giving back to the community. As the director of astronomy outreach, I am in charge of the popular Fisk-Vanderbilt Astronomy Road Show (a portable Starlab planetarium), among other things. Vanderbilt also has the Dyer Observatory (championed by Carl Seyfert!) that is primarily a public outreach instrument where we continue to show people the wonder of the universe.

Erika **Grundstrom**

Director of Astronomy Outreach and Dyer Observatory Liaison at Vanderbilt University

Erika Grundstrom

A DAY IN THE LIFE OF ...

David Friedlander

Marc **Kuchner**

Astrophysicist at NASA's Goddard Space Flight Center in Greenbelt, Maryland

8:30 A.M. Get started early so I have time to work on my book, *Marketing for Scientists*. It's been a difficult year for astronomers and scientists of all kinds; money and jobs have been in short supply since the economic downturn. I'm writing this book to help my colleagues learn the marketing skills they need to get by.

10 A.M. Paperwork to do before my meeting in L.A. next week, then another one in Hawaii the following week. The supercomputer quarterly reports will be due while I'm away.

11:30 A.M. Attend "Exoplanet Club," our regular seminar series at Goddard about extrasolar planets. Take the speaker out to lunch.

1 P.M. Meet with my postdocs at Goddard. With Hannah Jang-Condell, I'm working on modeling images of a disk that looks like there's a planet embedded in it. With John Debes, I'm researching how interstellar gas can affect images of young planetary systems. With Chris Stark, I'm working on a "collisional grooming" model of the dust in planetary systems like the solar system. That's about one-third of the projects I'm juggling. They all have to do with interpreting images of planetary systems.

3 P.M. Teleconference to discuss the next big exoplanet-imaging mission with other NASA centers.

4:30 P.M. Meet with my postdoc, Thayne Currie, to plan a meeting at Goddard about images of planetary systems around nearby stars.

6:30 P.M. Go to the gym, then go home and try to write a new country song. Astrophysics is about searching for the truth; I like to say country songs are too, just with more dirt and less computers.

Astro**fascinations**

What fascinates you most about Saturn?

Saturn's rings — composed of particles as small as dust grains and as large as giant boulders — are magnificent. Ever since the two Voyager spacecraft flew by Saturn in the early 1980s, I've been fascinated by the intricate structure and delicate beauty of its rings. I vividly remember watching as data on spiral waves and narrow ringlets never seen before were plotted on yards of paper. We unrolled this plot on the floor of a long hallway and "walked" through Saturn's rings. I was hooked!

Fast forward 30 years, and I am still in awe. I proudly work on the Cassini mission, which has been in orbit around Saturn for 6 years. I am the "ring leader" when the Composite Infrared Spectrometer team studies the planet's famous rings in the thermal infrared and takes their temperature. One exciting discovery showed that a ring particle's temperature decreases as Sun exposure on a particle changes from half lighting to a partial crescent. Some particles must spin so slowly, perhaps only once in half a day, that their dark sides get cold!

I would love to be able to hold a ring particle in my hand and take it apart. Is it like a fluffy snowball on the outside, with a solid ice core in the center? Is it a snowball all the way through? Or is it something else? While humans can't be there, at least we have Cassini to help us answer some of these questions!

Linda **Spilker**

Cassini project scientist at NASA's Jet Propulsion Laboratory in Pasadena, California

Tom Spilker

Astro**ideas** *How well do we know Earth's ultimate fate?*

John Glaspey; Earth: NASA

Lee Anne **Willson**

Professor in the Department of Physics and Astronomy at Iowa State University

Our planet's fate will depend on when and how fast the Sun loses mass in its red giant stage, 6 or 7 billion years in the future. We know that Earth will go through a long period of being far too hot for human existence; what we don't know yet is whether it will end up vaporized inside the Sun or orbiting around the bright, large red giant version of our star.

Why don't we know the answer? Current data about the size of other stars at their largest stages suggest our star will be about the size of Earth's orbit when it reaches that final moment. If Earth is still in the same orbit at that time, it will wind up inside the Sun.

How would Earth move away from the Sun? Our star will ultimately lose about 45 percent of its mass back into space, most of it when it is at its brightest and biggest. If the Sun can lose 20 to 30 percent of its mass before it fills Earth's current orbit, then our planet's orbit would expand by the same percentage, and Earth would probably be far enough away to survive.

Models of mass loss from pulsating red giants (called Mira variables) suggest that most of the mass loss occurs too late to save Earth. However, we do not yet understand the observations of mass loss from some stars that are not yet that big and that bright, so it is still possible that Earth will escape, leaving a cold bare rock that could be inscribed "Humanity was here" orbiting a faint, small white dwarf star.

Letters

Closer to home

I have been serving a tour with the United States Army in Iraq for about 9 months as a combat medic. The long nights of working here have really helped me appreciate the night sky. For years, I read books about the universe and had an interest in particle physics and astrophysics. Then, one night I used a star map from *Astronomy*, and it helped me understand what I was looking at. Now I've become a helpless observing addict.

You often can find me borrowing a spotting scope from the snipers or staying up late after a guard shift to see what new objects are just rising on the horizon. In April, I spent an entire week waiting to catch a glimpse of Jupiter between sandstorms and sunrise. (Nobody could understand why I always wanted the late shift.) Now I know the sky well enough that I can easily point out constellations to my fellow soldiers, and it helps them feel like they're closer to home.

Ben Shiek

The constellation Orion and the bright star Sirius (at left) offer those stationed overseas a glimpse of familiar faces.

I'm excited to return home soon, try out my father's telescope, and hopefully get one of my own eventually. My wife already has 10x50 binoculars waiting for me to use while on leave.

Thank you for making *Astronomy* so easy to use. On several nights, it has made difficult situations easier because I can look up and see familiar faces. Please ensure your magazines keep coming out here. — **Ben Shiek,** Elk River, Minnesota

Always the first read

I have subscribed to *Astronomy* for many years. For the past several, I find that the first page I turn to when I get my magazine is Bob Berman's "Strange Universe." Although I'm an experienced amateur, his column often teaches me something new and always makes me think. Berman writes "Strange Universe" with such wit and humor that it has become my favorite regular column in *Astronomy* magazine. I hope you plan to keep this feature as a part of the publication far into the future. — **Ted Forte,** Virginia Beach, Virginia

A theory is just that

I'm writing in response to Michael E. Bakich's "10 crazy ideas from astronomy's past" (August 2010). He seems to think that because a theory is superseded by later experiment and observation, it is "entertainingly ridiculous" and the scientist who formulated it is "crazy" or "wacky." But it is the nature of science that a variety of hypotheses are proposed to explain puzzling experimental results or observations. These theories stimulate further experimentation and observation to confirm or disprove them. The fact that subsequent experiment and observation favors one theory and disproves another does not make the disproven theory crazy. In fact, this article insults the memories of Fred Hoyle, Hermann Bondi, Thomas Gold, Sir Joseph Lockyer, Jean LeVerrier, Fritz Zwicky, Christiaan Huygens, and Sir William Herschel.

Many of the hypotheses mocked in the article, such as the existence of the ether, were based not on direct observation but were instead inferences made to explain observations. Numerous modern theories published regularly in *Astronomy* magazine (like dark matter, dark energy, string theory, the Big Bang, and the Moon's formation) are also inferences about things not directly observed. Let us hope that you will not one day publish an article mocking these theories based on experiments and observations that will be done decades or centuries in the future.

— **Jack Kessler,** El Cerrito, California

A beautiful sight

My wife and I saw the July 11 total solar eclipse gloriously while atop a snow-covered mountain in El Calafate, Argentina, along with perhaps 200 other people. The colors were incredible — white and red with a hint of green. The eclipse featured a round corona, a small prominence at roughly 7 o'clock on the Sun's disk, and no clouds at all. A crescent Sun was visible for perhaps 3 minutes after third contact before sunset began. This was my 14th unobstructed total eclipse, but I have never seen anything like this one in terms of colors and spectacle. — **Richard Rosichan,** Miami Beach, Florida

Correction

The star cluster labeled Trumpler 1 on page 72 in the August 2010 Reader Gallery, should be IC 166. We apologize for any confusion. — ***Astronomy* Editors**

We welcome your comments. Send letters to Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

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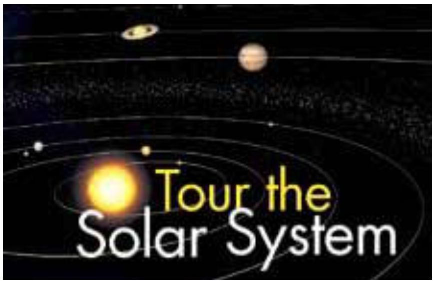

MULTIMEDIA

Eskimo Nebula

Dietmar Hager

Video: Winter observing targets for small telescopes A+

Senior Editor Michael E. Bakich highlights the objects you can see this winter using a small telescope, such as the Crab Nebula, the Eskimo Nebula, open cluster M35, and more.

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Lagoon Nebula

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StrangeUniverse

by Bob Berman

Extraordinary eclipse

December 20/21 promises to be a bizarre night for skywatchers.

The oddest celestial event? This year there's an easy winner. It's the millennium's first total lunar eclipse completely visible from all of North America and Hawaii. And whoa, beat the drums, it happens right on the solstice.

This was exactly the kind of spectacle that inspired the fun-loving Mayans to push their most annoying relatives off pyramids. (Does any scholar actually know how they selected people for sacrifices? "Annoying" seems logical.) These days, our own citizenry is much too overweight to engage in such energetic rituals. But if you're tempted, be sure to first check local ordinances before you perform even a single goat sacrifice.

At midnight December 20/21, we'll have the highest Full Moon until 2020. From the West Coast, that Moon will be in total eclipse at midnight — how cool is that? Observers in Key West will see the magical Moon straight up, an imperceptible ½° from the zenith. Count on crowds blowing conches at Sunset Pier at that overhead moment of 12:17 A.M. But like all Eastern time-zoners, they must wait 'til 1:32 A.M. for the eclipse's umbral beginning.

We'll also get a rare chance to gauge the Full Moon's brightness. During the night's first half, it defiles the sky with a creamy glow that obliterates everything fainter than 3rd magnitude. Then, if you live in the country away from streetlights and other light pollution, behold the metamorphosis. Drink in the glory of the winter Milky Way after the Moon's been reduced to a coppery phantom, with the visible star count boosted from 120 to 2,600.

Earth's shadow usually appears red. So the Moon becomes copper when fully immersed. Yet the initial "bite" as the event begins always looks inky black. Culprit: our retinas. When the sunlit portion is still fat and brilliant, our eyes underexpose the shadowed part. As you watch the eclipse progress, it's fun to note when the ebony starts becoming reddish, about halfway through the event.

Browse the "Strange Universe" archive at www.Astronomy.com/Berman.

The eclipsed Moon doesn't *have* to be red. It can be pale pink, beige, or even black so that it vanishes altogether. It all depends on clouds and dust around Earth's edge, or limb. This is the only occasion when a celestial body gives us a report card about our planet. Coppery red means everything is normal. Black means dust from the Iceland volcano and perhaps China's industrial pollution has dirtied our air big time. Green means you didn't set the alarm and are dreaming the whole thing.

This was exactly the kind of spectacle that inspired the fun-loving Mayans to push their most annoying relatives off pyramids.

Now for the ancient debate over equipment. People often fail to appreciate things that are free, so maybe they'll find this event enhanced through their most expensive telescope and largest 14-pound eyepiece. In my opinion, however, a lunar eclipse looks best with either the naked eye or else image-stabilized binoculars.

The Moon will occupy a very special place in the heavens that night. Our sky is a carnival of intersecting planes. There is the flat plane of our solar system seen edgewise, defined by the ecliptic. Then there is our galaxy's disk, the Milky Way. These eternal planes meet and cross at the Taurus-Gemini border. Astoundingly, a third plane called the solstitial colure — the sky-circling meridian running through the celestial poles in the precise direction of Earth's tilt — is right there, too.

It's an implausible three-way intersection. And yet that is where — within a few degrees — the Full Moon will stand during the eclipse.

So the Moon will be eclipsed while aligned with the galaxy's plane, Earth's tilt axis, and the centerline of our solar system all at once. Are you kidding? The Mayan priests would have tossed *extra* people.

The three sky-lines intersect in a teensy triangle that manages to surround NGC 2129, an open cluster 7,000 light-years away. Use your go-to telescope to locate those baby stars near the eclipsed Moon. Because the heavens will be nice and dark, deep-sky lovers take note: At mid-eclipse (3:17 A.M. EST), the ruddy Moon sits exactly halfway between Gemini's Rolls-Royce cluster M35 and Taurus' freakish Crab Nebula (M1).

Can you imagine the uproar from the paranoid and gullible if this notable display had coincided with the Mayan calendar flip? Then they'd be sure it's Armageddon-time. Happily, no eclipse or conjunction will occur 2 years from now on December 21, 2012. To show your gratitude, that non-event deserves an additional goat sacrifice.

One more thing. The Full Moon's hot surface aims infrared radiation our way like a bathroom heater. This makes Earth's lower atmosphere 4/100° warmer whenever the Moon is full. Will we lose this warmth during the eclipse? Let's bring along our high-tech lab thermometers that night and *really* puzzle onlookers.

Wait a minute. Onlookers? After midnight in December? No, you and I might just be alone for this one. Unless we move to Key West.

Contact me about my strange universe by visiting **http://skymanbob.com**.

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ObservingBasics

by Glenn Chaple

Feast on the winter crab

A supernova blast seen in 1054 continues to dazzle in December skies.

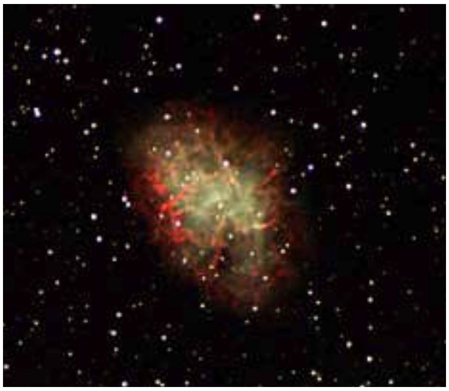
Bonsoir mesdames et messieurs! Mon nom est Charles Messier, et je … Excusez-moi! I forget that you are primarily an English-speaking audience. Let me start again. Good evening ladies and gentlemen! My name is Charles Messier, and I am known throughout Europe as a comet-hunter par excellence. A dozen comets bear my name, and it is my intention to uncover yet more of these cosmic wanderers.

I have been asked to speak to you tonight about the catalog that bears my name. In particular, I believe you wish to know about its first entry. On August 28, 1758, while following a comet discovered by Monsieur de la Nux, I came across a diffuse object near the southern horn of the celestial Bull. To my eye, it appeared whitish, without stars, and elongated like a candle flame — a new comet, perhaps? Subsequent evening observations revealed that the object was fixed relative to the starry background. A comet would have moved. I had been tricked! So, I endeavored to find and catalog other imposters so astronomers would not waste precious time on these faux comets. The nebula in Taurus became the first entry in my catalog.

I understand that you remember me more for my catalog than for my comet discoveries. I am honored, but please bear in mind that I never intended to document the heaven's finest nebulae. My catalog was first and foremost a list of comet pretenders. Now if you will excuse me, I must depart to my observatory lest my good friend and comet-seeking rival Pierre Méchain place his name on the next comet. Au revoir, mes amis!

Thank you, Monsieur Messier (that has a nice ring, doesn't it?). Anyway, the "Ferret of Comets" had no clue as to the nature of his first catalog entry other than that it definitely wasn't a comet. We now know that Messier's first catalog entry, which he referred to as a "candle flame," is in reality a supernova remnant — an expanding cloud of gas that represents the outer layers of an exploded star. As such, it's a relative newcomer to the cosmic scene. In fact, had Messier and his telescopes been around 1,000 years ago, he wouldn't have discovered Messier number 1 (M1) — it didn't exist!

Browse the "Observing Basics" archive at www.Astronomy.com/Chaple.



The Crab Nebula (M1) is one of the sky's most famous targets. It's an expanding cloud of gas and dust that represents the outer layers of a star that exploded in A.D. 1054. Cliff Wright

In A.D. 1054, skywatchers around the world, notably in China, noticed a brilliant star that suddenly appeared in the constellation Taurus. This "guest star" appeared brighter than Venus and was visible in broad daylight for 3 weeks. After 21 months, it dimmed to the point where observers could no longer see it.

In 1731, 27 years before Messier cataloged M1, the English amateur astronomer John Bevis discovered a nebulous object during a telescopic survey of Taurus. As telescopes improved in size and optical quality, astronomers were able to scrutinize M1 in increasing detail. An 1844 sketch by William Parsons, the Third Earl of Rosse, bore such a crablike appearance that M1 was thereafter known as the "Crab Nebula."

The connection between the supernova of 1054 and the Crab Nebula came to light during the early 1920s when astronomers discovered the Crab Nebula is expanding at a rate of 930 miles (1,500 kilometers) per second. Calculating back showed that the expansion began some 900 years earlier, close to the time of the 1054 supernova. The "guest star" of 1054 and the Crab Nebula were already known to share the same general location in Taurus. Connection made!

But why read about the Crab Nebula when you can see it for yourself? It's bright enough to be visible in the smallest of telescopes, as long as you observe from a rural or suburban area on a clear moonless evening. Attach a low-power eyepiece to your telescope and point it toward Zeta (ζ) Tauri. Keeping the star in the field of view, begin a slow circular search. You should come upon a small oval smudge of light about a degree northwest of this star. This is the sight that greeted Messier's eyes 2½ centuries ago.

Don't find it very interesting? Think again! At its greatest dimension, the Crab Nebula spans 10 light-years — more than the distance separating us from the star Sirius. In the heart of this vast gaseous cloud lies a neutron star — the remnant of the once massive star whose cataclysmic demise created the cloud. To get an idea of the astonishing nature of a neutron star, picture the Sun suddenly compressed until its diameter is just 12 miles (20 km). Now imagine this super dense, city-sized sphere spinning 30 times per second. As you gaze at the Crab Nebula, try to visualize this bizarre stellar corpse at its center. Not so boring, is it?

Like its planetary nebula cousins in the Messier Catalog (numbers 27, 57, 76, and 97), M1 won't be around forever. As it expands and dissipates, the Crab Nebula will become increasingly hard to see. Thousands of years from now, Earth's population will know it only through ancient written and photographic records.

Questions, comments, or suggestions? E-mail me at gchaple@hotmail.com. Next month: the Double Cluster. Clear skies!

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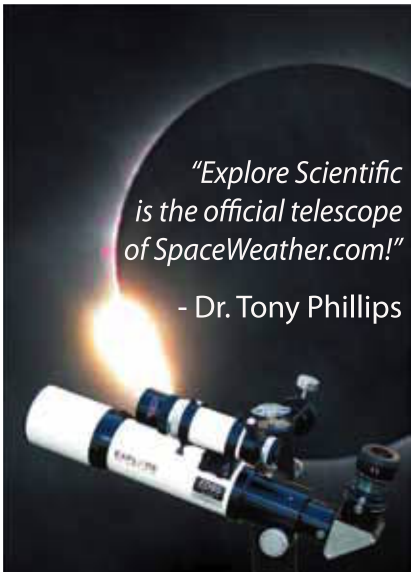
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SecretSky

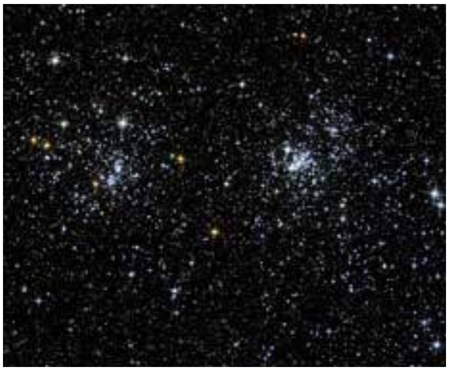
by Stephen James O'Meara

Two great double clusters

Perseus offers not one but two dazzling displays for observers who seek them out.

Go outside on a crisp, clear mid-December night around 9 and face north. If you're under a dark sky, the Milky Way will form a long frosty trellis arching over the North Star from east to west. Despite the Milky Way's prominent position, it doesn't "punch" the eye like the summer Milky Way — it's more of a visual caress. That's because we're now looking away from the stellar mayhem around our galaxy's center and toward the more subdued spiral structure at its outer edges.

But if you turn your binoculars to the top of the trellis and gently sweep across its rich star fields, you should encounter the Great Cluster of Perseus. Better known as the Double Cluster, this twin starry spectacle is an uncontested champion in visual splendor; aside from the brilliant Pleiades in Taurus, no other star cluster in the heavens compares. Plus, did you know that Perseus has more than one double cluster? More on that later.

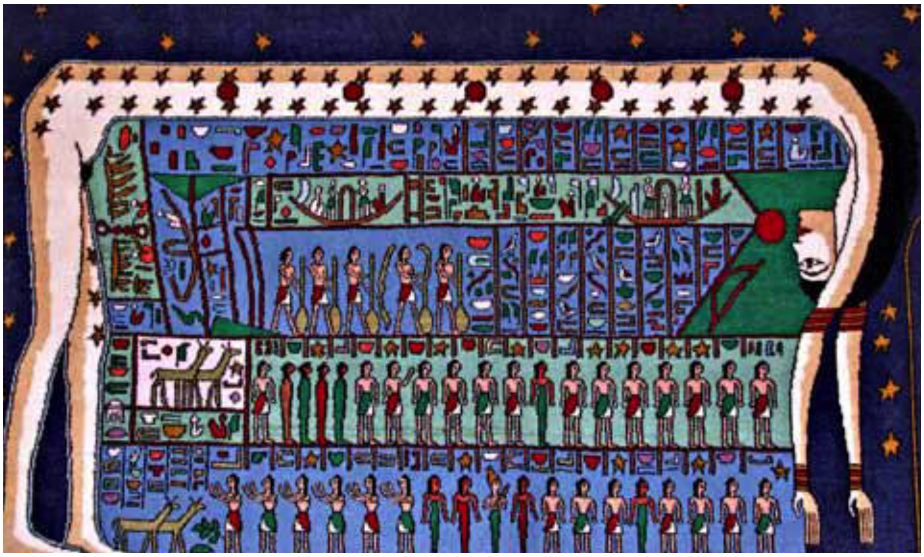


The Double Cluster, also called the Great Cluster of Perseus, may not be the only binary open star cluster in Perseus. Thomas V. Davis

Nut's fuzzy navel

Seen through the eyes of an ancient Egyptian, the northern trellis would be Nut (pronounced noot), mythological mother of the night. Depictions of this sky goddess show her body filled with stars, arching over Earth and its inhabitants, protecting them from the chaos beyond. Seen under the above perspective, the Double Cluster lies in her highly exaggerated body.

Sightings of the Double Cluster date to pre-telescopic times. The earliest known record belongs to the Greek astronomer Hipparchus (c. 190–120 B.C.), who called its combined light a "cloudy spot." Other pre-telescopic skywatchers also saw the cluster pair as a single nebulous patch. In his 1603 *Uranometria* star atlas, Johann Bayer labeled that spot Chi (χ). Bayer also placed the label "h" nearby. Celestial cartographers of the mid-19th century attributed "h" to NGC 869 (the pair's western component) and Chi to NGC 884 (the eastern one), giving us their current designations. But as Daniel W. E. Green and I proposed in 2003, "h" probably originally identified a faint nearby star, not NGC 869.



Stephen James O'Meara library

The ancient Egyptians depicted the Milky Way as Nut (pronounced noot), a mythological mother of the night, whose star-filled body arches over the sacred north in a protective posture.

Separation anxiety

Despite the woes of light pollution, skywatchers from the suburbs and some cities have spied the Double Cluster with their unaided eyes. It's one of the more intricate galactic details accessible using that method. This month, with the clusters so high in the sky, I'm interested in whether *you* can detect both clusters individually and without aid.

To find them, start by looking roughly midway along an imaginary line between 3rd-magnitude Delta (δ) Cassiopeiae and similarly bright Gamma (γ) Persei. The Double Cluster's position marks the handle of Perseus the Hero's diamond sword. Look for a cloudy knot of light in the folds of the Milky Way; once you think you've got it, use binoculars to confirm the view. The clusters should appear as two distinct flurries of starlight spread across nearly 1° of sky. Once you're certain of their location, lower your binoculars and concentrate on the region with your unaided eyes. To separate the two, try using direct vision.

The task is not as simple as it sounds. First, listed magnitudes for the cluster components vary significantly — from 3.5 (NGC 869) and 3.6 (NGC 884) to 5.3 and 6.1, respectively. In February 1998, I estimated the naked-eye brightness of the individual clusters as magnitude 4.5 for NGC 869 and 5.7 for NGC 884. If my estimates

Browse the "Secret Sky" archive at www.Astronomy.com/OMeara.

The beautiful Double Cluster in Perseus is on display (the double knot of white at top) in this unenhanced view of the Milky Way arching over north. Stephen James O'Meara

are correct, then the cluster's eastern component may present a challenge if the sky is too bright. But my estimates could be off, so don't let that stop you from looking.

I suspect the real challenge will be to "untrain" your night vision. Trained eyes will want to avert their gaze to collect as much light as possible; it's what eyes do in the dark. But you should use direct vision in this situation, which will send light to your eye's tightly packed central cone cells, resulting in greater resolution.

Do not stare at the clusters' location for too long. This causes eye fatigue and will end up actually diminishing the view. Instead, take short looks, collect your thoughts in between, and remember to breathe. Also, try looking in deep twilight about 45 minutes after sunset — around the same time that the brightest stars in Cassiopeia start popping into view. Doing so will reduce the clusters' contrast against a dark sky.

More twin delights

As I mentioned earlier, Perseus (somewhat unusually) harbors more than one double star cluster. The other, less-familiar pair is NGC 1528 and NGC 1545, which lie 1.6° east-northeast and 2.3° east (respectively) of 4th-magnitude Lambda (λ) Persei. You'll be able to find this star in the curved southeastern extension of the brighter segment of stars near Mirfak (Alpha [α] Persei).

Both clusters shine around 6th magnitude, and 1.5° separates them. Unfortunately, only NGC 1528 makes a decent naked-eye challenge under a dark sky. It is also the only one of the two readily visible in binoculars.

The problem with NGC 1545 is that its soft, fuzzy form lies only ½° east-northeast of a pair of 5th-magnitude stars, which interferes with the view. Perhaps this explains why the two clusters are not as well-known as they should be.

Nevertheless, both star clusters are a delight to see through a telescope, especially because many will show them in the same field of view at low power. But are they physically related, like those in the Double Cluster may be?

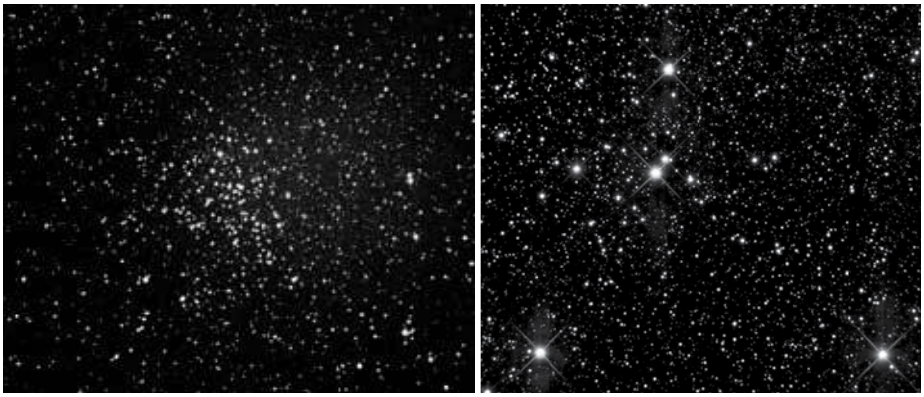
Studies show that both NGC 1528 and NGC 1545 not only share a common distance from the Sun (about 2,500 light-years) but are also of the same intermediate age (roughly 250 million years). They may be traveling through space together and not simply a chance alignment on the sky.

If we accept the distances to NGC 1528 and 1545, these clusters lie about 3 times closer to our Sun than the Double Cluster, which would explain why we see them separated in the sky about 3 times farther apart. But the jury is still out on whether NGC 1528 and 1545 form a true binary pair. If they do, then Perseus holds the distinction of being the only constellation in the heavens with two *binary* (not just apparently double) open star clusters.

"A number of astronomers have noted that the Milky Way Galaxy seems to contain very few binary star clusters," says Brent Archinal, a co-author of *Star Clusters* (Willmann-Bell, 2003), "even though such pairs or even triple clusters seem common in other galaxies such as the Magellanic Clouds."

(By the way, in 1963, Russian astronomer Klavdiya A. Barkhatova, then of the Ural State University, argued that NGC 1528 and 1545 made up part of a *triple* star cluster with NGC 1513 — an 8th-magnitude object about 2° southwest of the pair. But modern studies put NGC 1513 at a distance of 4,700 light-years, making it nearly twice as far.)

As always, let me know what you see. Send reports to someara@interpac.net.



Lee C. Coombs (NGC 1528); Martin Germano (NGC 1545)

Both members of the other double star cluster in Perseus (and a potential binary pair), NGC 1528 (left) and NGC 1545, shine around 6th magnitude, making for more formidable targets.

December2010 **Einstein lives** An August 12 paper in *Science* Express describes the discovery of an isolated pulsar by the volunteer computing project Einstein@Home.

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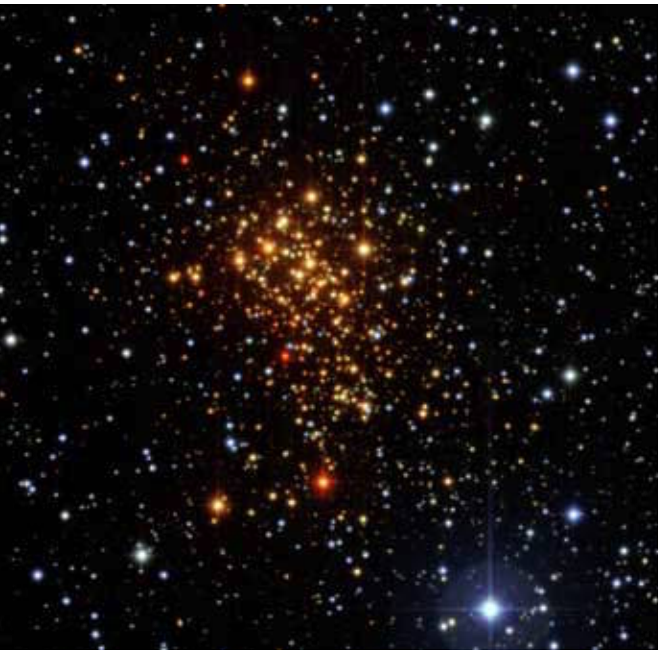
Star's mass indicates it should have been a black hole



Stellar hangout. Super-star cluster Westerlund 1 contains mammoth suns. Included in the group is magnetar CXO J164710.2–455216, which astronomers believe formed from a star with 40 times our Sun's mass. ESO

Galactic star clusters serve as stellar laboratories because the member stars were all born at nearly the same time. A star's mass determines not only its age but also how it will die. While studying Westerlund 1, the closest super-star cluster, scientists found that an unusual stellar remnant called a magnetar formed from a star so massive that it should have instead produced a black hole. Their results will appear in a future issue of *Astronomy & Astrophysics*.

Astronomers know of about 16 magnetars. After a massive star goes supernova, the leftover core becomes a neutron star. A magnetar is a neutron star with a magnetic field some million billion times stronger than that of Earth.

"Because the lifespan of a star is directly linked to its mass — the heavier a star, the shorter its life — if we can measure the mass of any one surviving star, we know for sure that the shorter-lived star that became the magnetar must have been even more massive," says team leader Simon Clark of The Open University in the United Kingdom.

The team studied a binary star system in Westerlund 1 whose objects' orbits and velocities are related to their masses. They learned that the star that became magnetar CXO J164710.2–455216 must have had at least 40 times more mass than our Sun. Astronomers had suspected that stars above about 25 solar masses would produce black holes.

"This therefore raises the thorny question of just how massive a star has to be to collapse to form a black hole if stars more than 40 times as heavy as our Sun cannot manage this feat," says co-author Norbert Langer of Bonn University in Germany. — **LIZ KRUESI**

22 Neptune's new Trojan asteroid

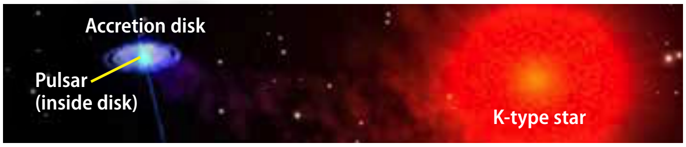
22 Two more for Kepler

23 How binary asteroids form

24 Is the Moon shrinking?

25 Dust around binary systems may be planetary remains

Companion star eclipses pulsar for first time



NASA/GSFC

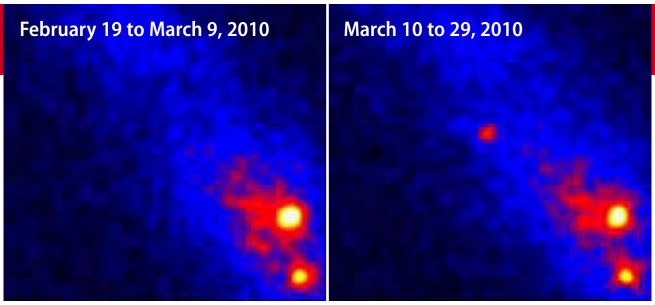
Out of the way. Neutron star Swift J1749.4–2807 is the first known pulsar to undergo eclipses from its companion, a normal star.

An unknown signal in April from the constellation Sagittarius the Archer turned out to be an X-ray pulsar, according to a July 10 paper in *The Astrophysical Journal Letters*. The source is part of an unusual binary system with a main sequence (normal) companion star eclipsing it.

The pulsar, designated Swift J1749.4–2807 (J1749 for short), is a quickly spinning neutron star — the tiny, dense leftover of a supernova. Previous observations established J1749 as part of a binary system, with the tiny pulsar stealing gas (or accreting it) from its normal-sized partner.

"This is the first time we've detected X-ray eclipses from a fast pulsar that is also accreting gas," says co-author Craig Markwardt of NASA's Goddard Space Flight Center. Discovering this system takes scientists one step closer to understanding the internal structures and mechanics of neutron stars, which are still largely mysterious. — **BILL ANDREWS**

Gamma rays come from novae, too



Sudden signal. In March, Fermi's Large Area Telescope captured gamma rays from the position of nova V407 Cyg. This is the first time astronomers have detected such high-energy radiation from this class of object. NASA/DOE/Fermi LAT Collaboration

Astronomers got a surprise during recent routine data processing from the Fermi Gamma-ray Space Telescope. They discovered gamma-ray emission associated with a nova — a star that undergoes a sudden brightening because of a thermonuclear blast on its surface. Scientists had long thought novae couldn't generate such high-energy radiation. The finding appeared in the August 13 issue of *Science*.

In the early hours of March 11, amateur astronomers in Japan first noticed white dwarf V407 Cyg was 10 times brighter than it had appeared several days earlier. This star has a companion red giant that leaked material into space via stellar wind. The gas accumulated on V407 Cyg's surface. Eventually, the material became so dense and hot that it underwent a thermonuclear explosion. This didn't blow the star apart (like a supernova), but temporarily brightened it.

"A few days later, automatic processing of data from Fermi's LAT [Large Area Telescope] alerted us to a new high-energy gamma-ray source at the same location as the nova," says Teddy Cheung of the Naval Research Laboratory (NRL) in Washington, D. C., lead author of the study. The astronomers think the surface explosion caused a shock front containing high-speed particles and ionized gas and, thus, magnetic fields. The resulting fields accelerated the particles to extreme speeds. As those particles slammed into the red giant's wind, they produced gamma rays.

"We know that the remnants of much more powerful supernova explosions can trap and accelerate particles like this, but no one suspected that the magnetic fields in novae were strong enough to do it as well," says co-author Soebur Razzaque of the NRL. — **L. K.**

NASA/ESA/The Hubble Heritage Team (STScI/AURA)/K. Cook (Lawrence Livermore National Laboratory)

A stunner in the Coma cluster

Standout object. Near the center of the Coma cluster of galaxies lies brilliant spiral NGC 4911. Such clusters are densely packed, which means collisions and mergers are destined to occur. Gravitational interactions with nearby galaxies are distorting NGC 4911's outer arms. Such contact also initiates star formation, seen in this image as the pink regions within NGC 4911's arms. Eventually, the galaxy will merge with another to form a giant elliptical. Astronomers with the Hubble Space Telescope released this image August 10. — **L. K.**

QUICK TAKES

PLANETARY PULSE

Saturn's aurora (its northern lights) pulses about once per saturnian day, in conjunction with the radio waves emitted from its poles, according to an August 6 paper in *Geophysical Research Letters*.

GLOW FOR IT

NASA announced August 2 that the source of a puzzling infrared glow coming from dusty regions in space is a flat "nano-sized" molecule called polycyclic aromatic hydrocarbon, a common compound on Earth.

COMMENDABLE DATING

The Meteoritical Society awarded Planetary Institute founder William K. Hartmann its 2010 Barringer Medal July 29 for his work developing methods to determine planets' ages.

SOLAR SURPRISE

Research in the August 26 *Geophysical Research Letters* suggests changing solar energy levels may shrink Earth's outer atmosphere.

DARK FUTURE

Astronomers have improved their estimates of the universe's mass and energy by using a galaxy cluster as a cosmic magnifying lens to study dark energy for the first time, according to an August 20 paper in *Science*.

IN THE CLOUDS

An upcoming paper in *The Astrophysical Journal* on unusual exoplanet HR 8799b suggests young gas giant planets are more clouded with dust than currently theorized.

A METEORITE'S SECRETS

The solar system may be up to 2 million years older than thought, according to a *Nature Geoscience* study that dated minerals within an ancient meteorite. It was published online August 22.

SOLAR SOLUTION

Changes in the Sun's "conveyor belt," which circulates material on its surface, may have helped cause the recent unusually long solar minimum, according to research published July 30 in *Geophysical Research Letters*.

PLANETS EVERYWHERE!

The European Southern Observatory announced August 24 that its HARPS instrument discovered a system with at least 5 (and up to 7) planets orbiting Sun-like star HD 10180.

Sneaky Trojan. Distant Neptune already boasted six Trojan asteroids in its Lagrange point L4 (ahead of the planet's orbit), but now astronomers have discovered one in the hard-to-study L5 position. NASA/JPL

Neptune's new Trojan asteroid

Astronomers have discovered the first Trojan asteroid in a specific stable zone named Lagrange point L5 within Neptune's orbit. Trojan asteroids, named after the legendary military ploy from the Trojan War, join a planet along its orbit at the two stable Lagrange points — areas where the Sun's and planet's gravitational pull exactly cancel each other out. The asteroid is thus virtually stationary with respect to the planet.

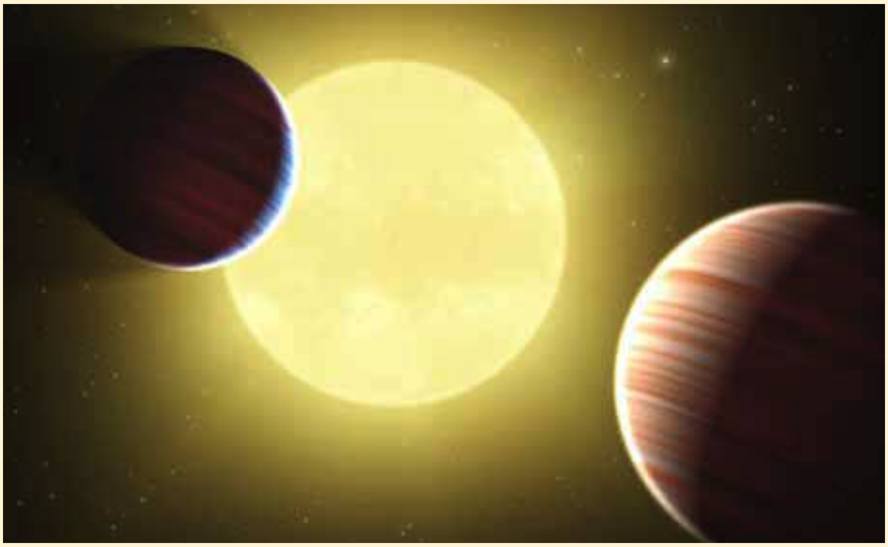
While Neptune has six known Trojans in its L4 region, ahead of the planet, this is the first Trojan discovered in the difficult-to-observe L5 region behind it. The research appeared online August 12 in *Science* Express.

"We estimate that the new Neptune Trojan has a diameter of about 100 kilometers (60 miles), and that there are about 150 Neptune Trojans of similar size at L5," says Scott Sheppard of the Carnegie Institution. "This makes Neptune Trojans larger than about 50 kilometers (30 miles) more numerous than those bodies of similar size in the main asteroid belt between Mars and Jupiter." The reason scientists have found so few Neptune Trojans currently is because they're so far away and harder to spot.

Jupiter and Mars are the only other planets known to have any Trojan asteroids, valued by astronomers because they may provide hints for solving mysteries in planetary formation and migration. — **B. A.**

SPACE SCIENCE UPDATE

Two more for Kepler



Light blockers. The Kepler spacecraft discovered a planetary system that's orientated edge-on to us, as pictured in this illustration. Kepler 9 is home to two Saturn-sized exoplanets and possibly one Earth-sized world. NASA/Ames/JPL-Caltech

The planet count keeps rising. In June, scientists with NASA's Kepler mission announced they identified 706 extrasolar planet candidates, including five systems with more than one possible world. Then, on August 26 in *Science* Express, they revealed the first official find from this dataset: The spacecraft had discovered two extrasolar planets orbiting the same star.

The Kepler spacecraft stares at more than 150,000 stars in a 100-square-degree field of view. It looks for tiny changes in brightness that signal a planet passing in front of (or transiting) the star from our point of view. Once they have candidate planets, astronomers then use other telescopes to further analyze the object to rule out any false positives. They used the Keck Observatory in Hawaii to confirm the new planetary system.

The star, designated Kepler 9, appears to have roughly the same mass as our Sun and a radius about 1.1 times that of our star. The two confirmed planets are Saturn-sized, but that's where the similarities end. Kepler 9b orbits its star just 13 million miles (21 million kilometers) out, while Kepler 9c orbits some 21 million miles (34 million km) from its star. Compare that to Mercury, which orbits the Sun from an average distance of 36 million miles (58 million km).

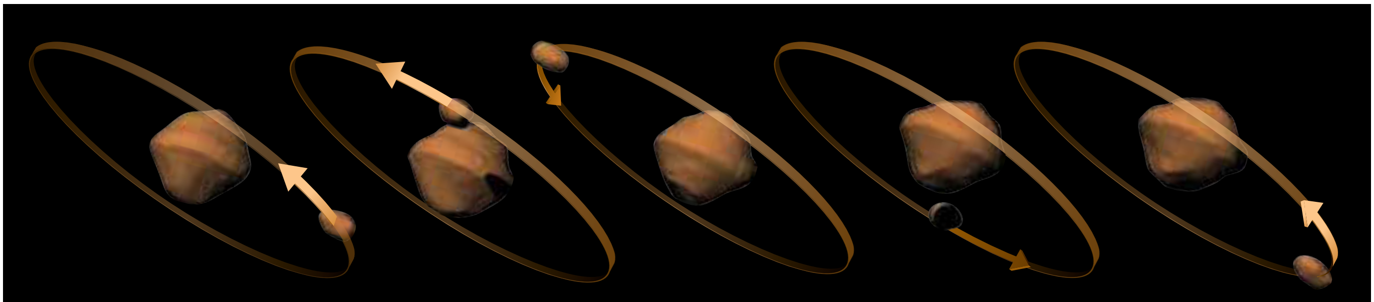
The scientists wrote in their paper that these exoplanets likely formed farther out and slowly migrated inward as the planetary system evolved.

Kepler's new finds zip around their star: the inner world in just 19.2 Earth days and the other in 38.9 Earth days. Kepler 9b and 9c orbit in almost a 2:1 resonance, meaning for every one orbit the outer planet makes, the inner completes two. In the data, astronomers have seen successive transits of the worlds vary slightly. "We can actually see evidence of the gravitational interaction of these two planets through the deviations in their transit times," says Matthew Holman of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts.

After subtracting the data from Kepler 9b and 9c, astronomers found the signature of another possible exoplanet with an orbit of just 1.6 days. This world would be much smaller, with a radius about 1.5 times that of Earth. The candidate planet's mass is somewhere between 1 and 7 Earth masses, but researchers need additional observations to confirm the object is indeed a planet and not a background eclipsing binary star system.

Finding multiple-planet systems is important because "rich systems like this one will be the best laboratories for understanding how planets form and how planetary systems evolve," says co-author Timothy Brown of Las Cumbres Observatory Global Telescope, Goleta, California. By the time Kepler completes its observing run, which will be no earlier than November 2012, it will likely have detected quite a few more multiple-planet systems. — **L. K.**

No water on the Moon? A lunar analysis in the August 6 issue of *Science* indicates that the Moon may be almost entirely devoid of water, a finding in contrast with much recent research.



Rubble buddies. Binary asteroids form during a process called "rotational fission": Sunlight causes an asteroid to spin faster until it splits apart. One such binary system is shown here. The objects then separate from each other at relatively low velocities. *Astronomy*: Roen Kelly; asteroid images: Steve Ostro (NASA/JPL)

How binary asteroids form

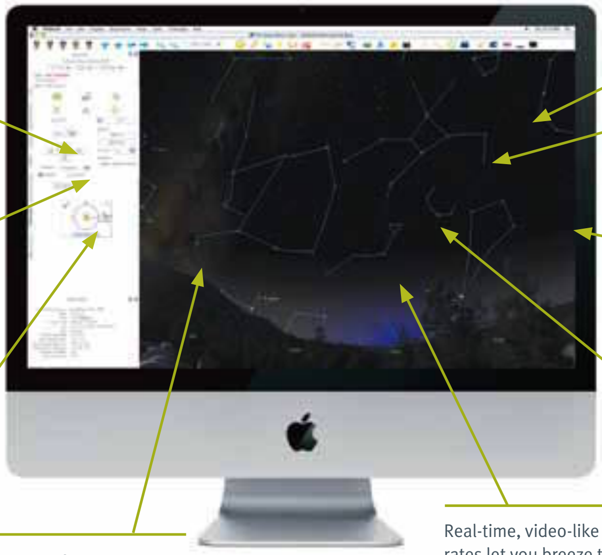
Sunlight can slowly speed up a small asteroid's rotation, like pinwheels in wind. When it spins fast enough, the body can split into two pieces that orbit each other, says an international team of astronomers in the August 26 issue of *Nature*. Over time, such binary asteroids separate and become two lone objects, instead of one system, orbiting the Sun.

The scientists studied the relative brightness of 35 asteroid pairs. (The system's brightness can tell astronomers about the two objects' relative sizes, spin rates, and shapes.) They also tracked the orbits of all pairs back roughly 1 million years and found that the two objects met up in 31 cases.

As they analyzed those specific pairs, the researchers found the smaller object consistently was less than 60 percent of the larger one's size. This measurement aligns with the "rotational fission" theory, developed in 2007. This model states that sunlight can speed up an asteroid's rotation enough so that it breaks into two pieces, where one is no more than 60 percent the other's size.

Over time, "the smaller guy steals rotational energy from the bigger guy, causing the bigger guy to rotate more slowly and the size of the orbit of the two bodies to expand," says study co-author Daniel Scheeres of the University of Colorado at Boulder. "If the second asteroid is small enough, excess energy allows the pair to escape from each other and go into their own orbits around the Sun." — **L. K.**

TheSkyX Professional has landed.



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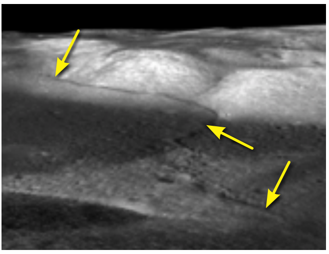
Solar speed One of the fastest coronal mass ejections, or solar flares, in recent years occurred August 1, with speeds above 2.2 million mph, NASA announced 3 days later.



NASA/GSFC/Arizona State University

Lunar shrinkage. A long, arching cliff interrupts the Moon's surface in this terrain model made from Lunar Reconnaissance Orbiter images.

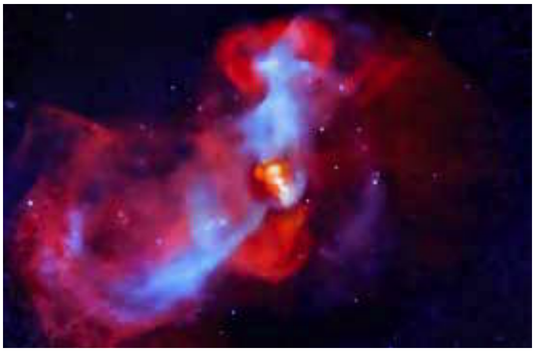
Is the Moon shrinking?

NASA's Lunar Reconnaissance Orbiter once again showed its scientific worth, providing images that scientists say prove the Moon shrank in the relatively recent past, and may still be shrinking even now. The research, which appeared in the August 20 issue of *Science*, uses newly found cliffs on the lunar crust to show just how recently, and how much, the Moon may have contracted.

"We estimate these cliffs, called lobate scarps, formed less than a billion years ago, and they could be as young as a hundred million years," says lead author Thomas Watters of the Center for Earth and Planetary Studies. "Based on the size of the scarps, we estimate the distance between the Moon's center and its surface shrank by about 300 feet (90 meters)."

Astronomers have long suspected the Moon had shrunk somewhat after its formation some 4 billion years ago, and might still be contracting today. These lobate scarps are young enough to indicate recent tectonic activity, and sufficiently widespread to be a Moon-wide phenomenon. As it cooled over the years, the Moon's mantle and surface contracted, creating large cliffs where a section of the crust breaks and juts out over another. Most of them end up with a semicircular or lobe-shaped look (hence the term *lobate*), but just why they take this shape remains unknown. — **B. A.**

Active galaxy's jets slowing star formation



X-ray (NASA/CXC/KIPAC/N. Werner, E. Million, et al.); Radio (NRAO/AUI/NSF/F. Owen)

Active center. Giant elliptical galaxy M87 harbors an active central supermassive black hole. The hot surrounding gas (shown in blue-white) should fall toward the galaxy's center and cool to form new stars. However, the black hole's jets emit radiation with such high energy that they seem to be pushing the cooler gas away. Researchers with the Chandra X-ray Observatory and the Very Large Array radio telescope announced August 18 that they have observed shock waves caused by the emission. — **L. K.**

BRIEFCASE

Looking for bubbles

Scientists have deployed a dark matter detector called a bubble chamber more than a mile underground at the Sudbury Neutrino Observatory in Ontario, Canada. They predict dark matter particles will leave bubbles in their paths through the liquid. The group, based out of the Chicago, Illinois, area, will install a second chamber in a few months. — L. K.

The sound of stars

By examining star HD 49933's acoustic fluctuations for 187 days, astronomers have detected the signature of starspots, areas of intense magnetic activity on the star's surface. "As [HD 49933] moves through its starspot cycle, the tone and volume of the ringing changes in a very specific pattern," says Travis Metcalfe of the National Center for Atmospheric Research. The team's findings appeared in the August 27 issue of *Science*. — L. K.

Double the view

Astronomers with the Multiple Mirror Telescope in Arizona have extended the use of adaptive optics to a wider field of view. Turbulence in Earth's atmosphere causes stars to twinkle; this phenomenon hinders observations. However, by using lasers to mimic starlight, astronomers can tilt their telescope mirrors to cancel out the flickering. This method has been used for only extremely small fields of view. An article in the August 5 *Nature* details an adaptive optics technique to capture an area 2 to 3 times wider than before, allowing for a larger region of a celestial object to be studied at once. — L. K.

25 years ago in *Astronomy*

December 1985

In the December 1985 issue, Bridget Mintz Register examined "The Fate of the Moon Rocks" in a profile of the Lunar Curatorial Facility at the Johnson Space Center in Houston, Texas. Register described how the staff gleaned as much information as possible from the out-of-this-world samples while keeping them pristine and uncontaminated.

Ultimately, Register wrote, the samples could aid in a return to the Moon. "The samples in hand can not only tell us where the scientifically interesting sites are, but also … how such a lunar base could become a true step to the colonization of space."

10 years ago in *Astronomy*

Astronomy
3-D UNIVERSE

December 2000

The December 2000 issue included a perennially futuristic element: 3-D pictures. Three stories took part in the issue's "3-D Extravaganza," which also included a pair of familiar red-and-blue glasses bound in the magazine.

First, Robert Naeye invited readers "Back to Mars," featuring images that, despite their beauty, were "created by a scientist for science," according to Mars Pathfinder project scientist Matt Golombek.

Next, Kelly Kizer Whitt and Akira Inaka helped with "Seeing the Depths of the Universe," including 3-D images of the Pleiades star cluster (M45), Comet Hale-Bopp, the Horsehead Nebula (B33), and the Andromeda Galaxy (M31).

Finally, then-Managing Editor David J. Eicher reminded readers "Earth is a Planet, too," presenting "a mere sampling from the finest archive of topographic Earth imagery ever produced," by NASA's Shuttle Radar Topography Mission. — **B. A.**

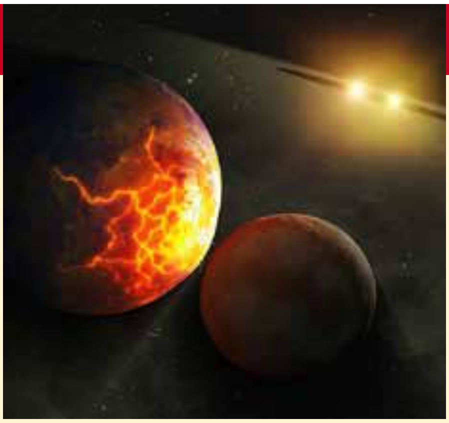
Dust around binary systems may be planetary remains

Binary star systems with tightly orbiting stars may be capable of hosting planets, even within the habitable zone where life could theoretically exist, but recent research shows it might be a chaotic place to visit. A new study in the September 10 *The Astrophysical Journal Letters* describes a large, unexpected amount of dust around close binary pairs and suggests it may be the remains of enormous collisions between planets.

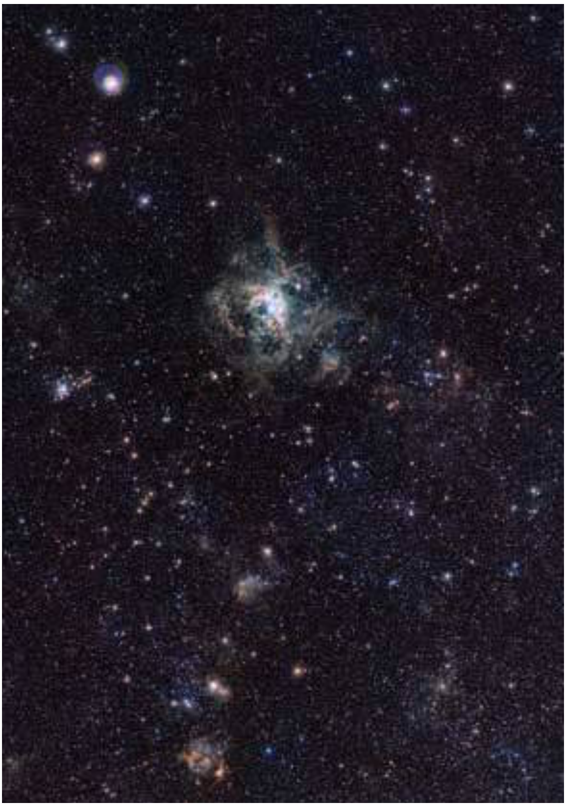
"Our data tell us that planets in these systems might not be so lucky — collisions could be common," says co-author Jeremy Drake of the Harvard-Smithsonian Center for Astrophysics. "It's theoretically possible that habitable planets could exist around these types of stars, so if there happened to be any life there, it could be doomed."

The research looked at a class of binary systems named after the prototype star RS Canum Venaticorum, in which the stars orbit each other about as closely as possible, some 2 million miles (3 million kilometers) apart. The stars spin so fast that their magnetic fields create powerful stellar winds, wreaking havoc on the system's dynamics and throwing any stable planetary orbits into disarray. The three such systems under study were old enough that dust would have blown away from the stars unless something — such as planetary collisions — replenished it.

"These kinds of systems paint a picture of the late stages in the lives of planetary systems," says co-author Marc Kuchner of NASA's Goddard Space Flight Center. "And it's a future that's messy and violent." — **B. A.**



Dusty grave. The environment around some binary stars may be so chaotic, it turns planets to dust through collisions, as shown in this artist's illustration. JPL/NASA



ESO/M.-R. Cioni/VISTA Magellanic Cloud survey/Cambridge Astronomical Survey Unit

Admiring the Tarantula Nebula's neighbors

Spying the spider. The Tarantula Nebula (NGC 2070) shines brightly in this spectacular new image from the European Southern Observatory's Visible and Infrared Survey Telescope for Astronomy in Chile, released August 11. Also known as 30 Doradus, the nebula is a star-forming region home to some of the most massive stars yet known and lies about 160,000 light-years distant, within the Milky Way's neighboring Large Magellanic Cloud. The image, covering an area nearly 5 times as large as the Full Moon, displays the nebula at center, the star cluster NGC 2100 to the left, the remnant of Supernova 1987A to the right, and a series of star-forming regions below. — B. A.

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How stars form

Stars begin as clouds of cold gas that transform into blazing hot fireballs. Here’s what scientists know about the process — and what they’re missing. **by Liz Kruesi**

Look up at the night sky from anywhere on Earth and you’ll see stars. Because these objects are so widespread, you’d think astronomers would know how they form. And, for the most part, researchers do.

A gas cloud collapses into something much smaller and hotter — a star. But questions arise when delving into the details of the formation process. Nearby massive stars, other sun-forming clouds, and even the Milky Way’s spiral structure affect how stars form. And more problems arise when astronomers analyze the formation of groups of suns.

To help connect the dots, some scientists are simulating star formation using sophisticated computer models, while others are incorporating more observations in different wavelengths and piecing together three-dimensional images of what they view in the sky. Together, they are mounting an attack to figure out exactly how these familiar objects form.

It starts with a cloud

Clouds of gas and dust, called the interstellar medium (ISM), fill our galaxy. One of many processes triggers at least one slight overdensity in a giant molecular cloud, beginning the star formation process. “The overdensities in molecular clouds that we identify as ‘cores’ are almost certainly produced by the turbulent motions present in the clouds,” says Mark Krumholz of the University of California, Santa Cruz.

If many hot, bright stars are close together, their intense radiation could create turbulence in the ISM. Close approaches of galaxies and interstellar clouds can also create instabilities. When a supernova explodes, it causes a shock front, a region of compressed gas directly

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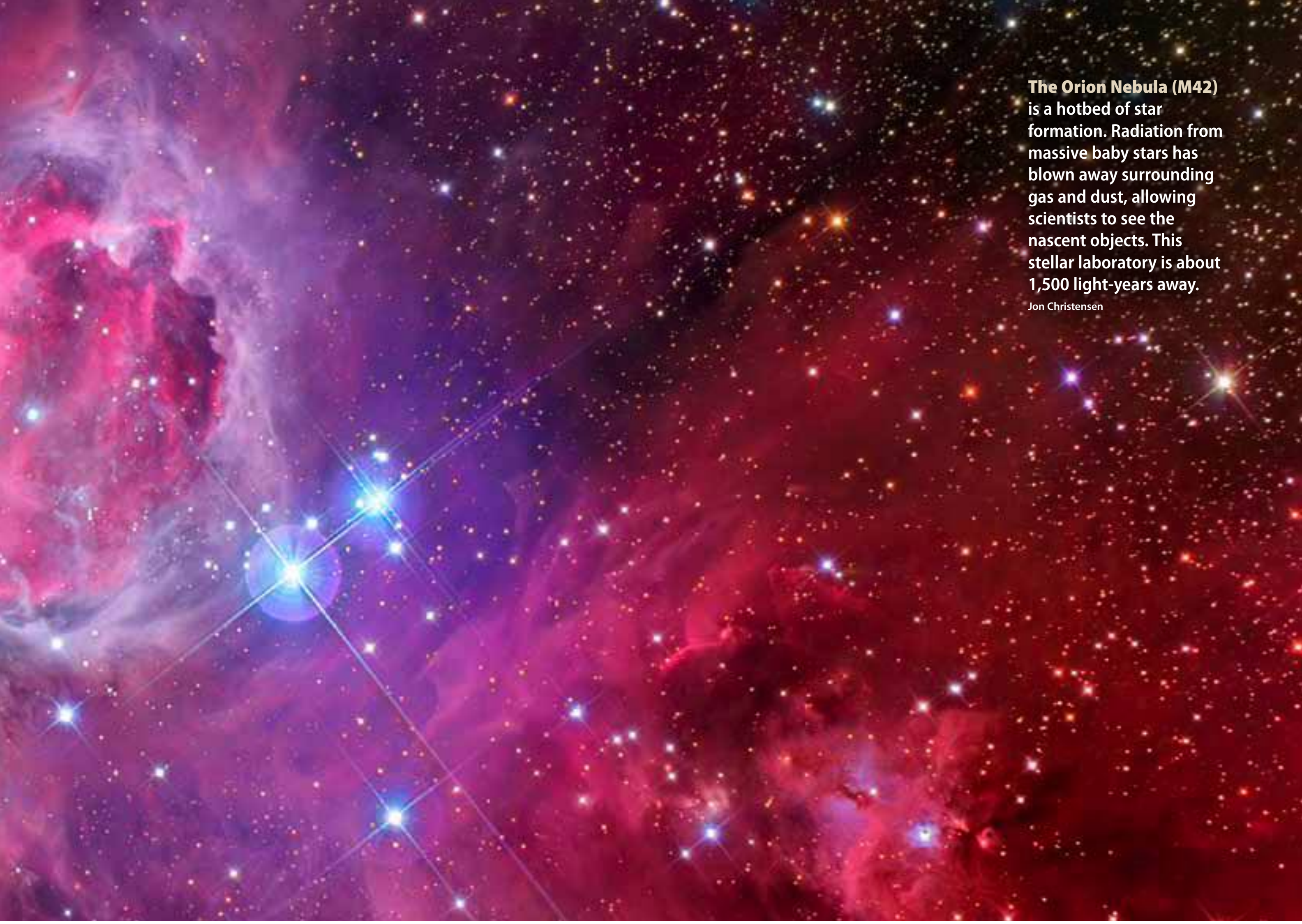
Liz Kruesi *is an associate editor of* Astronomy. *Her June 2010 article “What makes stars tick?” explained what goes on inside stars.*



The Orion Nebula (M42) is a hotbed of star formation. Radiation from massive baby stars has blown away surrounding gas and dust, allowing scientists to see the nascent objects. This stellar laboratory is about 1,500 light-years away. Jon Christensen

ahead of the expanding shell. Spiral density waves sweep around the Milky Way, compressing material as they pass — a phenomenon that creates our galaxy's spiral structure. In fact, as astronomers observe other spiral galaxies, they see regions of young stars along these galaxies' arms. This compression can thus initiate star formation.

After the overdense seeds have been planted, the cloud of interstellar gas becomes unstable and fragments. Almost all cloud clumps that eventually become main sequence stars — those that fuse hydrogen to helium in their centers — do so within millions of years.

The rich get richer

Gravity pulls material into the denser region, so the cloud gets more massive and begins to contract. It spins faster due to conservation of angular momentum, the same way a figure skater's spins speed up as she brings her arms closer in.

The core's temperature increases as more material "settles" inward. Any region of hot gas will have some ions — particles that have lost or gained electrons and therefore have a positive or negative electric charge. Charged particles can move only in certain directions in a magnetized region. Hence, the galaxy's magnetic field combined with the gas cloud's ions cause the clump's rotation to slow but not stop — otherwise we wouldn't have stars.

Next, a cloud that will eventually become Sun-sized shrinks to a much smaller region — about the size of the solar system — after tens of thousands of years. The central portion's temperature is now about 10,000 kelvins. Astronomers call it a protostar.

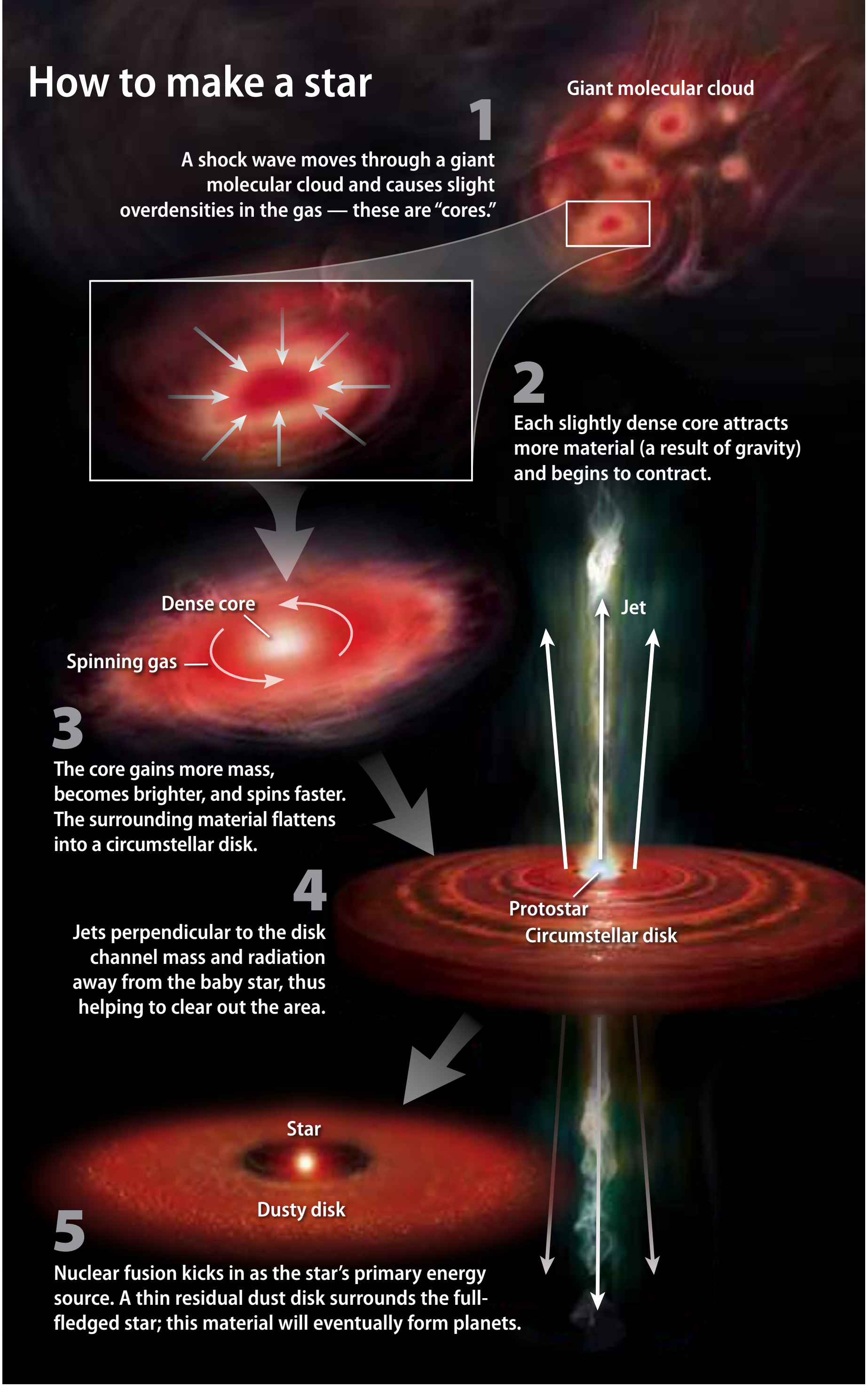
Baby stars

A protostar is more luminous than the star it will become because it is much larger (some hundreds of times) and thus has a greater surface area from which to radiate energy. Although it's enrobed in dust, the baby star's bright luminosity still lets astronomers see it. The protostar continues to gravitationally attract more material, contract, and heat up internally. As the nascent star's outer surface shrinks, it becomes less luminous.

NASA and The Hubble Heritage Team (AURA/STScI)

A protostar can spew out jets of material perpendicular to its gas and dust disk. This process, along with accretion, depletes much of the remaining material in the disk. The Hubble Space Telescope caught this baby star.

How to make a star



1
A shock wave moves through a giant molecular cloud and causes slight overdensities in the gas — these are "cores."

2
Each slightly dense core attracts more material (a result of gravity) and begins to contract.

3
The core gains more mass, becomes brighter, and spins faster. The surrounding material flattens into a circumstellar disk.

4
Jets perpendicular to the disk channel mass and radiation away from the baby star, thus helping to clear out the area.

5
Nuclear fusion kicks in as the star's primary energy source. A thin residual dust disk surrounds the full-fledged star; this material will eventually form planets.

Astronomy: Roen Kelly

The cloud and its central protostar spin faster, causing it to flatten into a "circumstellar disk." In some cases, the protostar produces a strong wind, which channels material out in the form of jets perpendicular to the disk. Magnetic fields also contribute to these jets, but researchers don't know exactly how. The radiation beams carry some mass away from the star and disk in a relatively short timescale (a few thousand years). The protostar also accretes much of the material that isn't blown off, leaving behind a residual disk likely to form planets.

The protostar's interior is now hot enough — about 1 million kelvins — to begin fusing deuterium to helium. Deuterium — also called heavy hydrogen because its nucleus contains one proton and one neutron, compared to hydrogen's one-proton nucleus — is the easiest nucleus to fuse. Hydrogen nuclei need higher temperatures to combine.

The protostar continues contracting, therefore increasing the density in its center. After its core reaches 10 million kelvins, it can fuse hydrogen nuclei into helium. It has then reached equilibrium, where the radiative energy from fusion perfectly balances the gravitational pull of its mass. It is now a full-fledged star.

Simulating a star

The star formation process includes many steps over millions of years. So how do outside factors affect the process? That's where computational modeling comes in.

Because scientists can't watch a star's entire formation, they simulate the process with supercomputers. The biggest question they hope these models will answer is why the mass distribution of newly formed stars varies little between sites of star formation — it's universal. But astronomers "do not understand where the average mass comes from, or what sets the distribution of masses around that mean," explains Krumholz.

Star formation models take into account the effects of thermodynamics, magnetic fields, radiative processes, and, of course, gravity. Recent simulations are also adding in "feedback" because stars affect their own environment. "This influence takes many forms: Young stars heat up the gas around them via their radiation, they push the gas around through their winds and jets, and massive stars can ionize the gas around them, causing it to blow away," says Krumholz.

In computer models, there is one key question. "Can you reproduce the properties of specific areas of star formation?" asks Alyssa Goodman of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts. "Under certain physical conditions, if you have a big molecular cloud, what's the most massive star that's going to form there? ... How clustered are the stars going to be?" The solutions depend on chemical composition, magnetic fields, ionization, a cloud's age, and other factors.

Peering into the nursery

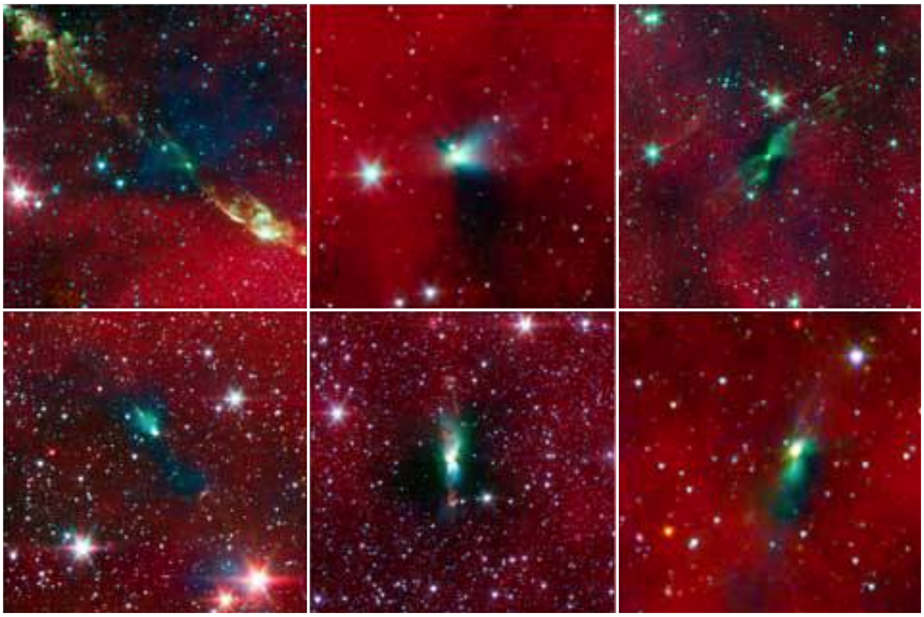
Astronomers use a range of wavelengths to observe star formation. The early stages (for example, as the interstellar cloud begins to contract) are observable in radio. The cores are too cold to emit visible and infrared radiation. (Higher energy, and shorter wavelength, corresponds to higher temperature; lower energy, and longer wavelength, to lower temperature.)

When looking for protostars, astronomers focus on infrared radiation. Stars emit in visible light, but we can't see that radiation because material surrounds the nascent star. Dust absorbs the light and radiates it in the infrared. So infrared satellites see the dust immediately encompassing the protostar.

The Spitzer Space Telescope, which looks for infrared radiation, has uncovered hundreds of protostars in large clouds. Now astronomers want to pierce even deeper and see the stages that come before protostars. But the gas is colder and therefore radiates at low energy, so the regions they're looking for are dim. They use slightly different tools, ones that detect "submillimeter" waves — far infrared into microwave.

Goodman's former graduate student Jaime Pineda and colleagues have succeeded in finding the best example yet of a core — the stage earlier than a protostar. The team detected a compact source embedded in cold gas that isn't visible in any wavelength more energetic than submillimeter.

Goodman's team is also at the forefront of reconstructing images of star-forming regions from observations. The team collects sky position data (which is 2-D from our view) and velocities for an entire molecular cloud. Then it pieces this information together into a 3-D model, which the researchers can analyze. Using this method, the team has discovered unexpected structures within clouds and even previously unseen star-forming regions.



These young stars are still within their collapsing clouds of gas and dust. The Spitzer Space Telescope imaged the dust immediately surrounding the early protostars — this material absorbs radiation from the stars and emits it in infrared. Astronomers know the top-left and top-center clouds house baby binary stars, and they believe the other four might as well. NASA/JPL-Caltech/J. Tobin (University of Michigan)

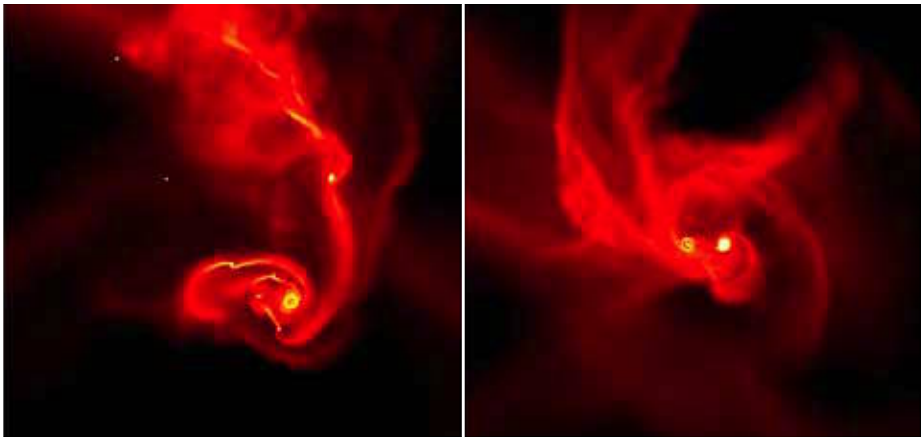
Other tripping points

From observations, astronomers know that stars tend to form most often in multiples. They think star clusters — which contain hundreds to thousands of stars — start out as a large cloud and fragment into many smaller clouds. But this creates a problem when divvying out the gas. Do individual cores steal material from different areas, or does each accrete gas only from its nearby vicinity? These two theories are called competitive accretion and gravitational collapse, respectively. As often is the case, scientists are split regarding which theory is right. And others say each of these processes may happen occasionally. Figuring out if one method beats the other is a hotly debated topic.

High-mass stars are also poorly understood, especially their formation. "Do these very massive stars form in a process that is simply a scaled-up version of the process by which low-mass stars form, or do they require some fundamentally different process to form?" adds Krumholz. Astronomers expect that these high-mass stars would blow away surrounding material, halting star formation.

Astronomers also aren't sure what the upper limit to the biggest stars' masses are, and even if there is one. For years, scientists believed stellar masses would max out at about 150 times the mass of the Sun. But this summer, a team of astronomers announced that it had found evidence of a mammoth exceeding the 150-solar-mass limit.

Scientists are also concerned that the galaxy's star formation rate seems awfully low. The rate they're finding is between 10 and 100 times lower than expected considering the amount of material available in giant molecular clouds. Are some star-forming regions more or less efficient? Astronomers aren't sure. But with new observational techniques, and constant upgrades to their simulations, they're on their way to answering this and other questions of star formation.



Astronomers are adding different feedback processes into their supercomputer simulations. The left image shows the model without feedback; the right shows it with. The white dots are stars or brown dwarfs. In the left image, too many brown dwarfs form for each star, while the radiative feedback model more closely matches observations of star-forming regions. Matthew Bate/University of Exeter, UK

Want to learn more about the innards of stars? Visit www.Astronomy.com/toc.

What's the

By analyzing the Sun's light, astronomers are learning about not only our star's makeup, but also the early solar system. **by Jim Kaler**

Th Pa U
Ni Co Cu
Rh Pd Ag
Ir Pt Au
Nd Pm Sm Eu Gd
Np Pu Cm
B C N
Al Si P
Ga Ge As
In Sn Sb
Tl Pb Bi
Dy Ho Er
Cf Es Fm
He
O F Ne
S Cl Ar
Se Br Kr
Te I Xe
Po At Rn
Tm Yb Lu
Md No Lr

We — our Sun, Earth, and selves — are the products of everything that happened before our creation. The initial event, the Big Bang 13.7 billion years ago, still affects us today, not only in the resulting expansion of the universe, but also closer to home in the very fabric of the Sun. To figure out the whole story of where we came from and how things got to be the way they are, though, we must turn to the stars that made us — and what made them.

A reduced history of the universe

In the beginning, there was hydrogen. Just 3 minutes after the Big Bang, hydrogen atoms — protons — and neutrons collided to create helium and a little lithium.

So it would have remained, but for the stars that condensed from the expanding milieu. The first stars were massive. Supporting themselves with nuclear fusion in their deep, hot cores, they transformed hydrogen into helium, then helium into carbon and oxygen, and these into yet heavier elements. When they got to iron — the end of the fusion line — they blew up as the first supernovae (technically classified as "type II" supernovae). In the explosion's cauldron, more fusion and other processes created nearly all of the periodic table. The detona-

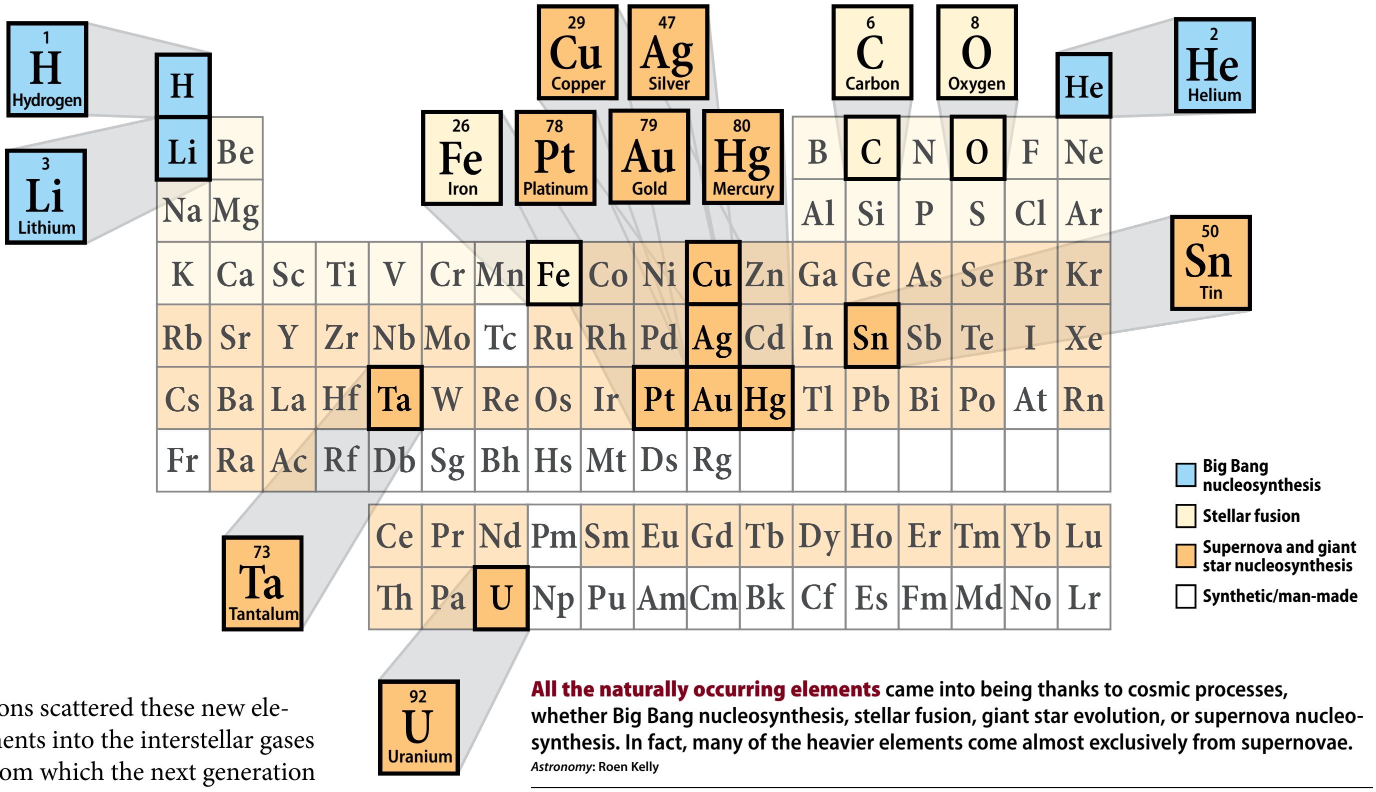
Jim Kaler, *professor emeritus at the University of Illinois at Urbana-Champaign, is a regular contributor to* Astronomy. *A past president of the Astronomical Society of the Pacific, he is also the author of more than a dozen books, most of them about stars.*

Sun made of?

2
He
Helium
4.0026
H
Hydrogen
1.0079
Li
Au
O
Oxygen
15.9994
Fe
H
Li
Fe
Au
O

The Sun has always served as our nearest laboratory in space, telling us more about the early universe and its makeup every time we study it in greater detail. *Astronomy*: Kellie Jaeger; NASA/GSFC/SDO (Sun); *Astronomy:* Roen Kelly (Big Bang, particles, elements)

Elemental origins



All the naturally occurring elements came into being thanks to cosmic processes, whether Big Bang nucleosynthesis, stellar fusion, giant star evolution, or supernova nucleosynthesis. In fact, many of the heavier elements come almost exclusively from supernovae. *Astronomy*: Roen Kelly

tions scattered these new elements into the interstellar gases from which the next generation of stars would form.

Dust from the explosions cooled the interstellar gases, which allowed for stars with a greater range of masses. The more massive ones again blew up, while those of lower mass became the more ordinary stars we still see today. When their fusing interiors stopped at carbon and oxygen, they shrugged off their outer atmosphere to expose their cores as the first white dwarfs. A few of those within close binary systems grabbed enough mass from their companions to exceed the white dwarf limit of 1.4 solar masses and again blew up as another kind of supernova ("type Ia").

Both kinds of supernovae sent ever more heavy stuff into space, and elements made inside the giants through more leisurely neutron capture were broadcast through their mighty winds.

Each generation of stars contains more carbon, oxygen, iron, and zinc. Elements beyond hydrogen therefore steadily build up as more stars create them, and their different origins dictate different growth rates for each element.

Then, 4.6 billion years ago, came a galactic milestone, at least for us: The Sun's birth, bringing with it some 9 billion years worth of previous element formation.

Astronomers can therefore look back in time using the Sun, which contains a record of the workings of the universe before it and Earth were born. The chemical composition of the star thus becomes a fundamental data point with which to test broad theories of stellar and galactic evolution. But how can we learn the chemistry of a fearsomely hot body 93 million miles (150 million kilometers) away? After all, we can't just send a satellite to "bite off" some and bring it home.

Meanwhile, back in the lab

Actually, it turns out we can, if we let nature do it for us. The inner planets and asteroids also carry the Sun's record of heavy elements. Earth won't serve because its surface has undergone numerous modifications, and the other planets are currently inaccessible. But the most ancient meteorites, originally from the asteroid belt, which have changed least since birth, will work — at least in part.

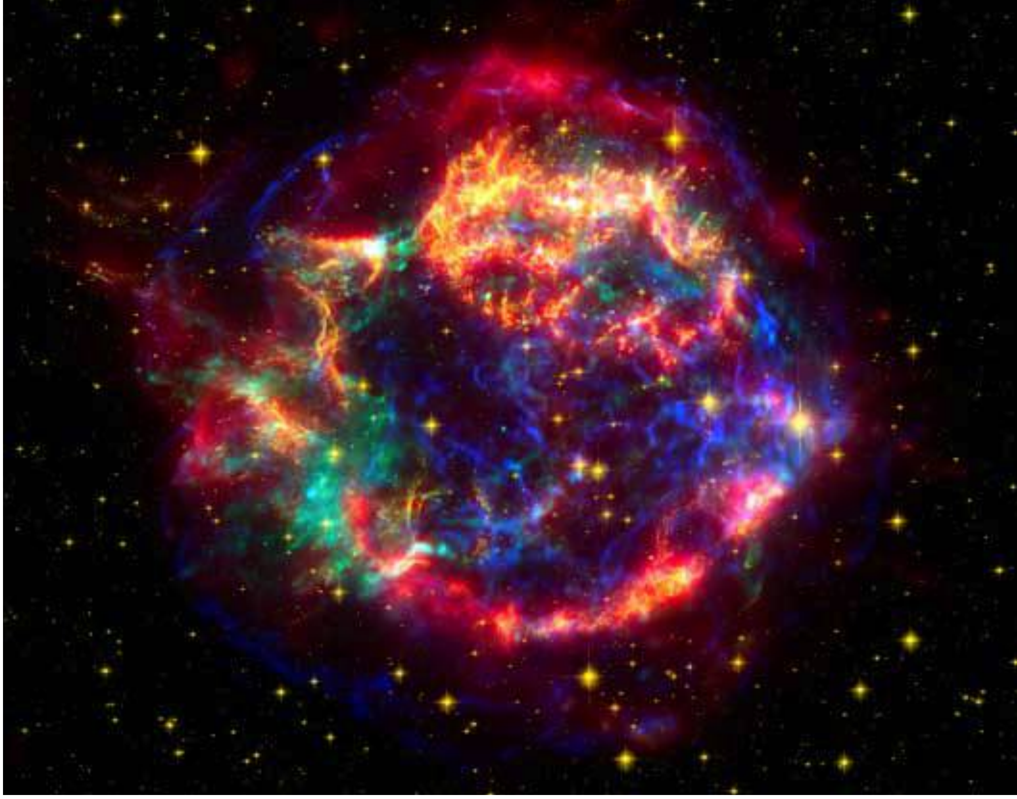
While studying asteroids (such as 951 Gaspra) through their meteorites yields insights into the solar system's formation, a lack of lightweight elements (such as hydrogen) means scientists must turn elsewhere to study the chemical makeup of the earlier universe. NASA

Astronomers take these pieces of the primitive solar birth cloud that have landed on Earth and bring them into the lab for precise analysis. Although we learn much about them and the solar system that created them, they have unfortunately lost — or never had — the lightest, most volatile elements. We want to compare abundances with hydrogen, but meteorites have none (except within their small amounts of water). Nor do they have helium with which to test the amount produced by the Big Bang. Nor is there much of any other noble gas such as neon or argon. To learn these details, we must turn to the Sun — and to the very heart of solar studies, the solar spectrum.

Show your colors

Light, which moves at 186,000 miles (300,000 km) per second in a vacuum, behaves as both a wave and a particle (called a photon) at the same time. The length of the wave — that is, the physical distance between wave crests — determines the color we see. In the visual spectrum, longer wavelengths of 700 billionths of a meter (nanometers) appear red, short ones of 400 nm appear violet, and all the other colors fall in between. Past the long side is the infrared, and past the short lies the ultraviolet. The amount of energy the wave/photon carries depends on the wavelength; violet light is almost twice as energetic as red, and ultraviolet proves downright dangerous (as anyone who's ever gotten a sunburn can attest).

From the light of the Sun comes a smooth rainbow of colors, their individual richness dependent on the average solar surface temperature of 5780 kelvins (9900° Fahrenheit). Spread the spectrum with a prism, and it breaks into hundreds, even thousands, of segments separated by dark gaps, or "lines." Each line is the result of a particular chemical element in the outer solar gases that absorbs the light from the continuous, unbroken spectrum the Sun generates. (For more on the absorption of light, see "Think positively (and negatively, too)" on page 34.)



The earliest stars created new, heavier elements than simple hydrogen and helium in their cores, and when they exploded as supernovae they scattered these materials out into the cosmos, as in the case of Cassiopeia A. NASA/JPL-Caltech/STScI/CXC/SAO/O. Krause (Steward Observatory)

Journey from darkness

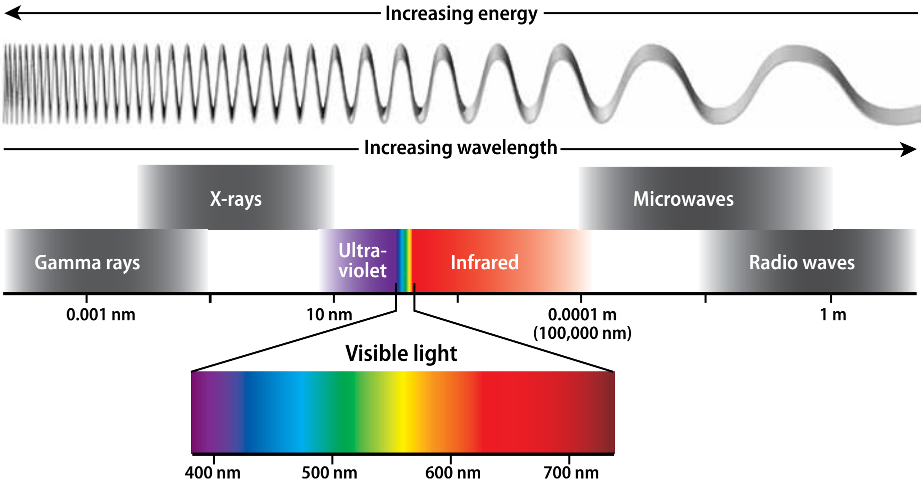
The amount of light removed from the solar spectrum by the absorption line — its "strength" — depends ultimately on the abundance of its parent element. But how do we determine that?

It's a tough job, as the number of steps is rather large. The strength of the line depends on two things: the number of atoms with electrons suited to absorb that color of light (the orbital "population"), and the likelihood that such an atom actually absorbs that light (the "transition probability," determined through lab experiments or calculation). Using theory and further experiments, we then relate the population (derived from the line strength) to the total number of atoms to get the elemental abundance.

All that effort requires a good model of the Sun. And therein lies the real problem. Absorption lines have width to them and thus, plotted on a graph of darkness against wavelength, a "profile." The Sun is not a hard ball at a specific, uniform temperature. What we see as the solar surface is actually a partially transparent layer — the "photosphere" — in which the temperature continuously changes from bottom to top. Most absorption lines are made at slightly different layers, and so at different temperatures. Indeed, each part of the absorption profile of a line is formed in a different layer at a different temperature. To relate line strength to the number of atoms producing it, we need to know how temperature relates to photospheric depth: the "temperature gradient."

To an extent, scientists can determine the temperature gradient using solar limb darkening. Because the Sun is a sphere, your line of sight at the edge, or limb, does not penetrate as deeply as when you look at the center. You therefore see cooler gases, and the solar surface looks dimmer and redder. We can also use models, which depend on calculations of the opaqueness of the gas. These in turn depend on, naturally, abundances.

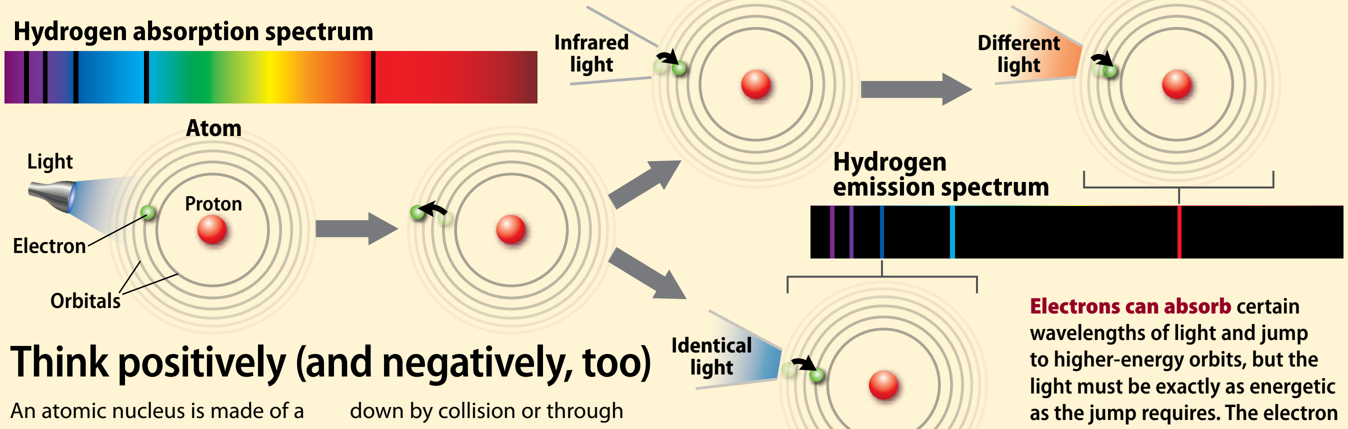
The electromagnetic spectrum



The color, energy, and wavelength (distance between wave crests) of light are all related. Yellow light, for instance, has a shorter wavelength than red light, so it is more energetic. *Astronomy*: Roen Kelly

To LTE or not to LTE

The amount of calculation involved in modeling the Sun is daunting. With no



Electrons can absorb certain wavelengths of light and jump to higher-energy orbits, but the light must be exactly as energetic as the jump requires. The electron can then drop down to the original orbit and emit the once-blocked light, or it can descend to a different orbit and radiate an entirely different kind of light. *Astronomy*: Roen Kelly

Think positively (and negatively, too)

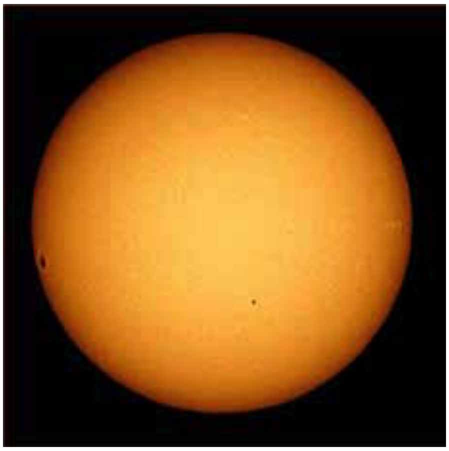
An atomic nucleus is made of a combination of positive protons and neutral neutrons. The number of protons determines the element. Hydrogen has one proton, carbon six, and uranium 92. Surrounding the nucleus is a cloud of “orbiting” negative electrons that balance the charge of the protons. We can vary the number of neutrons and electrons to produce isotopes or ions, respectively.

Although electrons orbit, they do not behave like planets. Instead, they are restricted to orbits with specified sizes and energies, with the ability to jump from one orbit to another, changing energy levels as they go. They can be bumped up and down by collision or through absorption and emission of photons. Usually it’s the outermost electron that does the job.

To move to an outer orbit requires that an electron absorb the right amount of energy, and it’s all or nothing: The energy of the photon must exactly equal the energy difference between orbits for an electron to make the jump. Remember, energy relates to a specific color, or wavelength, of light. Hence, in the Sun’s radiation, atoms of a particular kind within the partially transparent outer solar atmosphere can block that narrow band of color to produce a dark absorption line. The electron can then drop back down to the same orbit, releasing the energy at the same wavelength, or — by descending to a different orbit — it can radiate at a completely different wavelength.

Each kind of atom has anywhere from a few to thousands of allowed orbits, and each set is unique. Hydrogen is simple, iron a mess. The net effect is that every ion of every atom will imprint a different, and often complex and overlapping, fingerprint of dark lines on the radiation that emerges from lower solar layers. By using pure spectra from the lab combined with theory, however, we can identify the lines and tell what elements are in the solar atmosphere.

Working for more than a century, we have found 64 of the 90 or so natural elements within the Sun, with five more — the noble gases — added by examining other parts of the Sun or the solar wind. The rest are surely there, but their signatures are too weak to detect against the background of other lines. — *J. K.*



Astronomers can make use of limb darkening, where the Sun’s circular “edge” appears dimmer than its center, to gather information about the outer solar gases. Mila Zinkova

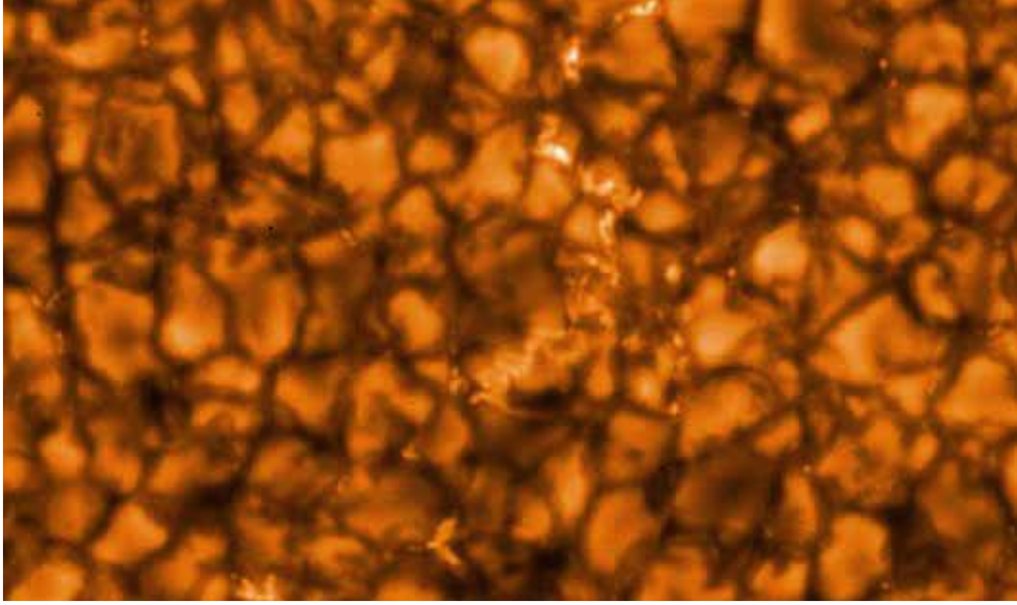
powerful computers, early modelers had to be content with simplicity, so they assumed the solar photosphere would be quiet and layered with smooth changes. Moreover, the solar gases were assumed to be in simple “local thermodynamic equilibrium” (LTE), in which each atomic process, whether absorption or collision, was exactly balanced by the opposite process.

The final results were reasonably close with amounts from meteorites, which use the equivalent solar values of silicon as a benchmark to fill in any blanks. And there are many. The lightweight element lithium (number 3) is extremely scarce in the solar photosphere, and there are no solar abundances for such well-known elements as iodine, platinum, mercury, and uranium (not to mention obscure ones like tellurium, tantalum, and rhenium).

But given advances in computing power and the quest for better absorption probabilities, we can improve the model, making it more complex so it can fit the actual solar conditions. The first to go was the assumption of LTE. Too many options exist for atomic processes to assume constant balance. To calculate the population of a given electron orbit therefore requires that all atomic processes and orbital interactions be taken into account, which significantly boosts the amount of calculation.

And then, have you ever actually seen the surface of the Sun? The photosphere is constantly in a roiling state of convection, with hot gases rising and cool ones falling, each in a cell the size of Texas. Temperatures depend on whether you look at the center of a cell, near an edge, or at a dark falling zone at the edge. (And don’t even think about sunspots.)

With the advent of powerful supercomputers, the latest developments involve 3-D models, in which the reality of convective motion, as well as non-LTE interactions, are taken into account. Ideally, each generation of model is more successful and realistic than the one that came before.



Convection cells dot the surface of the Sun, giving it a granulated appearance. Each cell, about the size of Texas, has its own cycle of heat and energy transport; the brighter centers are hot gases rising from below, and the darker edges are cooler gases falling back down. Hinode/JAXA/NASA/PPARC

The envelope, please

Even the simple models, however, when coupled with meteorite results, reveal some remarkable abundance patterns. Helium (determined through analysis of solar vibrations) comes in at 8.5 percent as abundant as hydrogen, which, given a bit of enrichment by previous stellar generations, fits with predictions made based off the Big Bang. Beyond that, the next most abundant element is oxygen (about 0.05 percent as abundant as hydrogen), followed closely by carbon, neon (obtained from the solar corona and wind), and nitrogen. All fit with what one would expect from current theories.

The light elements in between — lithium, beryllium, and boron — have low concentrations, which is no surprise because the stellar fusion process skips over them. Except for minimal Big Bang production, scientists now know these elements are produced in collisions between cosmic rays (high-speed particles) and interstellar atoms. Lithium is especially scarce in the Sun because convection pushes it downward toward the core where nuclear reactions destroy it (so the amount of Lithium provides a handy way to measure solar age).

Except for big dips at fluorine and scandium, elements after the carbon-nitrogen-oxygen (CNO) group see a general decline, with a final rise around iron, which makes sense given that the element is the end of energy-producing fusion. We then see a steep drop as we move to the elements created by neutron capture, whose abundances decline quickly with increasing proton number, but with rises around barium and lead. Superimposed on the whole abundance pattern is a jagged sawtooth shape in which even-numbered atoms are somewhat more plentiful than their odd-numbered neighbors, the result of a preference for paired protons in atomic nuclei.

So who cares?

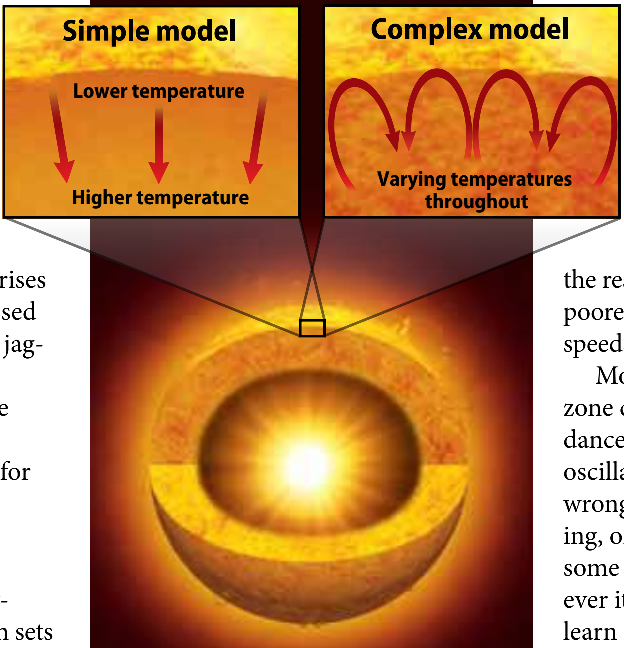
The results matter to just about everybody. The solar chemical composition sets the example by which other stars, our solar system, and even Earth are understood. It thus touches the very heart of our origins. Galactic evolution modelers use it to test their predictions, as do astrophysicists interested in nucleosynthesis — the making of heavy atoms from light ones. Interstellar astronomers use solar abundances to determine how often heavier atoms (considered "metals" by astronomers) condense on dust grains, which results in metal-depletion of the gas and which is important in understanding star formation. Deviations between solar abundances and cosmic-ray data reveal the interactions between these ultra-fast particles and the interstellar medium that produced the Sun, which tells us more about each. Of major importance, solar abundances are vital for calculating the cloudiness of solar and stellar gases, upon which theories of structure and evolution depend heavily.

The solar composition is crucial in understanding how the Sun — the basis for life — works. The new 3-D models drop the CNO abundances by 70 to 80 percent, which fits with results from other stars and with diffuse and local planetary nebulae.

Yet not all is well. Solar oscillations allow the determination of the speed of sound within the solar interior, which depends on chemical composition. The calculations of the expected speed using the results of new 3-D models give notably poorer agreement with the observed speeds than do earlier, simpler models.

Moreover, the depth of the convection zone calculated under the new abundances is less than that found from the oscillations. Nobody knows what's wrong. Either the models need improving, or the solar oscillation folks have some work to do. Or maybe both. However it works out, from its chemistry we'll learn more about the Sun and the stars that surround us, and thus of the universe of which we are all a part.

Solar models



Solar models once had to be simpler, using theories assuming smoothly changing temperature (left). In reality, the Sun is much more complex, and recent advances in computing have made more realistic models possible. *Astronomy:* Roen Kelly

Watch high-definition videos of the Sun at www.Astronomy.com/toc.

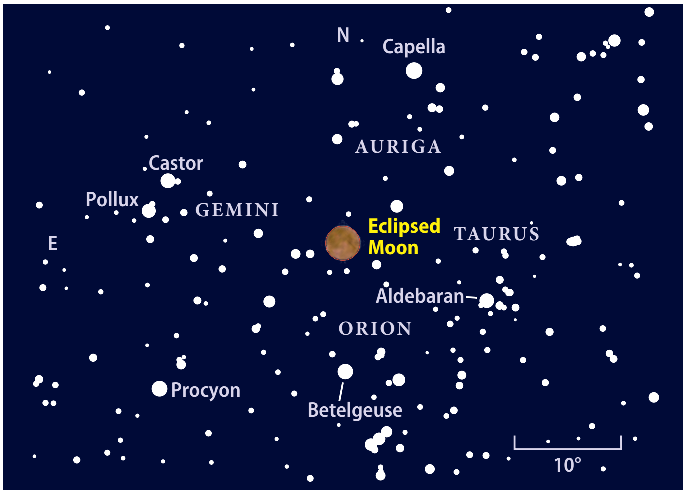
The Sky this Month

Martin Ratcliffe and Alister Ling describe the solar system's changing landscape as it appears in Earth's sky.

December 2010

Venus blazes before dawn

Earth's orange-red shadow will envelop the Full Moon December 20/21, just as it did during this February 2008 eclipse. Tunç Tezel



The totally eclipsed Moon December 20/21 lies in Taurus the Bull, near its border with Orion and Gemini. *Astronomy*: Roen Kelly

The first total eclipse of the Moon in nearly 3 years occurs the night of December 20/21. Weather permitting, people across North America will be able to see totality.

This spectacular event is one of many that fill December. Evening skies offer stunning views of Jupiter and Mercury, which shines through the western twilight in early December.

The innermost planet slips into the morning sky by month's end, where it joins Venus gleaming at its brightest and the always lovely Saturn. The reliable Geminid meteor shower adds to these treats in mid-December, contributing repeated exclamation points to an event-filled month.

Let's start our tour in the twilight sky after sunset, where **Mercury** lurks during December's first 2 weeks. On the 1st, the planet stands 6° high in the southwest 30 minutes after sunset. This coincides with Mercury's greatest elongation from the Sun (21°) and the peak of its evening appearance. (**Mars** lies half as high and is essentially invisible.)

Mercury shines at magnitude –0.4, bright enough to stand out against the twilight glow. Target the planet with your telescope, and you'll see a 7"-diameter disk that's slightly more than 60 percent lit.

36 The Moon in total eclipse 👁 👓 🔭
41 Meteor watch 👁
41 Rising Moon 🔭
42 When to view the planets 👁 👓 🔭
42 Jupiter adds a fifth moon 🔭
42 Comet search 👓 🔭
43 Locating asteroids 👓 🔭
43 The Moon joins Venus 👁 👓

👁 **Visible to the naked eye**
👓 **Visible with binoculars**
🔭 **Visible with a telescope**

A young Moon joins Mercury at the end of December's first week. On the 6th, our 2-percent-lit satellite appears 3° high and 5° to Mercury's lower right a half-hour after sunset. The next evening, a fatter crescent Moon lies 7° to the planet's upper left. A scope then shows Mercury's disk to be 8" across and 40 percent lit.

Mercury quickly slides out of sight and passes between the Sun and Earth December 19. A week later, the planet springs into the morning sky. By the 31st, it stands 10° high in the southeast 30 minutes before sunrise. It then shines at magnitude 0.2, noticeably brighter than 1st-magnitude Antares 12° to its right. A telescope shows Mercury's disk, which measures 8" across and appears one-third lit.

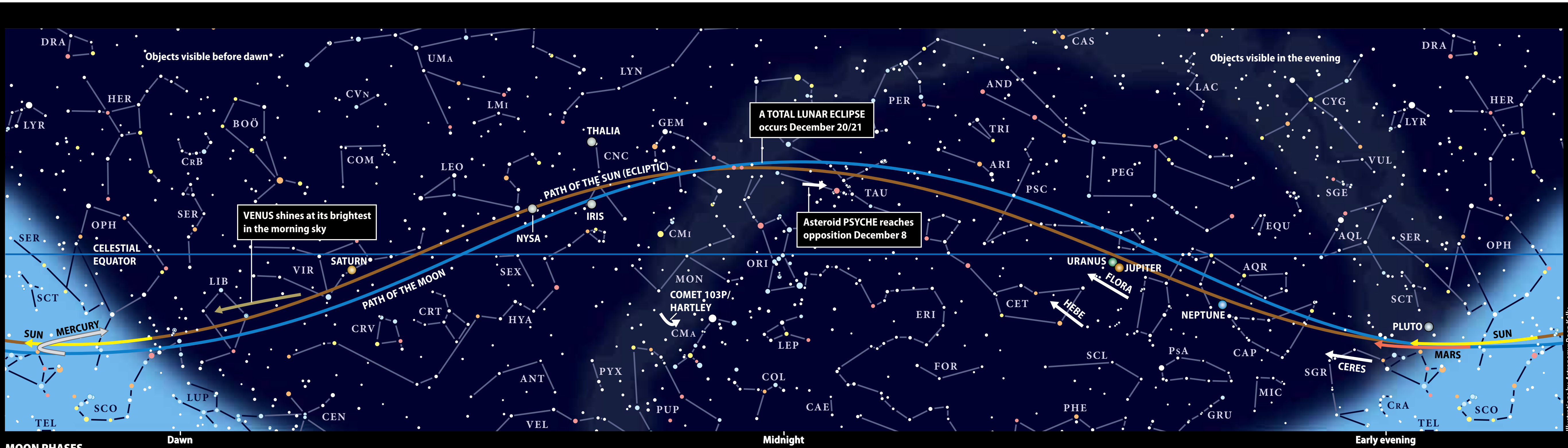
— Continued on page 41

Path of the planets

Planets in December 2010

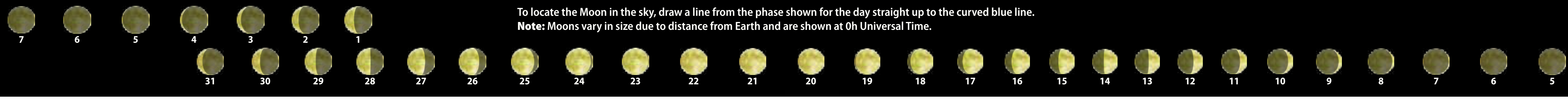
This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.

Astronomy magazine


DRA
Objects visible before dawn
UMA
LYN
CAS
Objects visible in the evening
DRA
HER
LYR
CVN
LMI
BOÖ
CRB
COM
THALIA
GEM
A TOTAL LUNAR ECLIPSE occurs December 20/21
PER
AND
LAC
CYG
HER
LYR
TRI
ARI
LEO
CNC
PATH OF THE SUN (ECLIPTIC)
PEG
VUL
SGE
SER
OPH
VENUS shines at its brightest in the morning sky
NYSA
IRIS
TAU
PSC
Asteroid PSYCHE reaches opposition December 8
EQU
AQL
SER
OPH
SER
CELESTIAL EQUATOR
CMI
SATURN
VIR
SEX
ORI
MON
URANUS
JUPITER
AQR
LIB
PATH OF THE MOON
COMET 103P/HARTLEY
FLORA
CET
SCT
SCT
HEBE
ERI
CRT
HYA
NEPTUNE
SUN
MERCURY
CRV
CMA
PLUTO
SUN
LEP
SCL
PSA
CAP
MARS
FOR
ANT
PYX
COL
SGR
CERES
LUP
MIC
SCO
PUP
CAE
PHE
CRA
CEN
GRU
SCO
TEL
VEL
TEL
Dawn
Midnight
Early evening

Illustrations by *Astronomy*: Roen Kelly

MOON PHASES


7
6
5
4
3
2
1
31
30
29
28
27
26
25
24
23
22
21
20
19
18
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12
11
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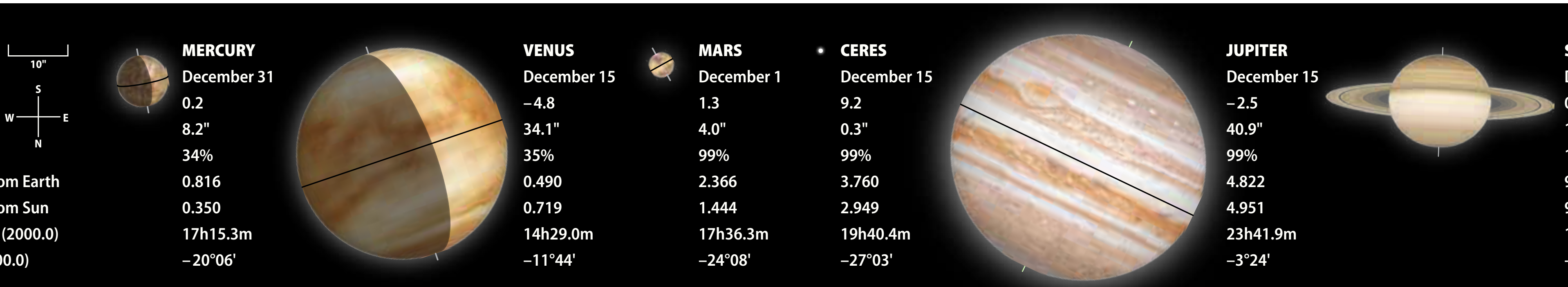
6
5

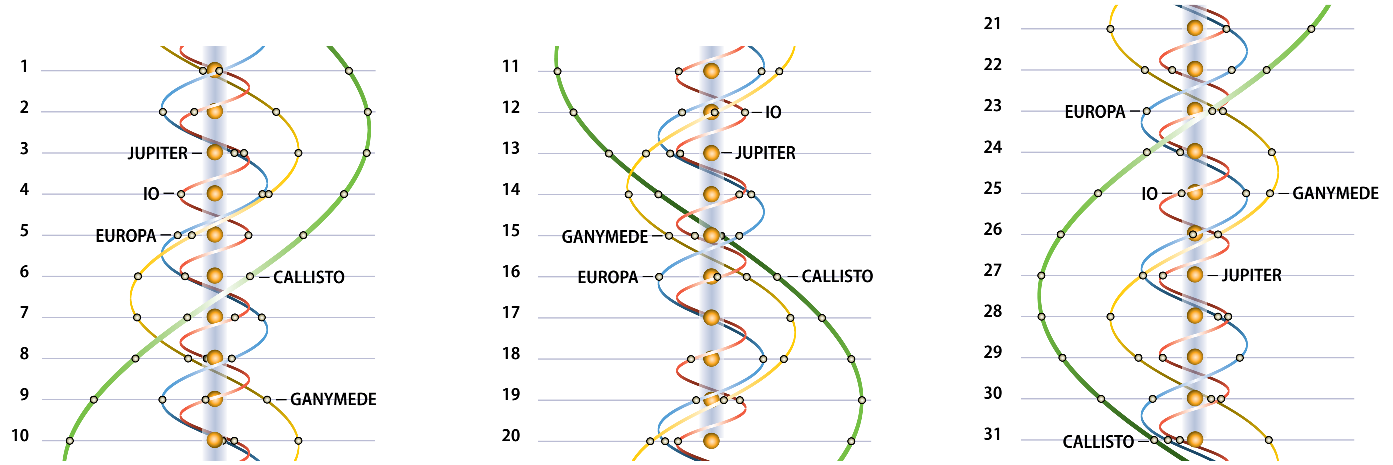
To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.
Note: Moons vary in size due to distance from Earth and are shown at 0h Universal Time.



PLANETS	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	December 31	December 15	December 1	December 15	December 15	December 15	December 15	December 15	December 15
Magnitude	0.2	–4.8	1.3	9.2	–2.5	0.8	5.8	7.9	14.1
Angular size	8.2"	34.1"	4.0"	0.3"	40.9"	16.8"	3.5"	2.2"	0.1"
Illumination	34%	35%	99%	99%	99%	100%	100%	100%	100%
Distance (AU) from Earth	0.816	0.490	2.366	3.760	4.822	9.918	20.001	30.442	32.906
Distance (AU) from Sun	0.350	0.719	1.444	2.949	4.951	9.580	20.090	30.014	31.946
Right ascension (2000.0)	17h15.3m	14h29.0m	17h36.3m	19h40.4m	23h41.9m	13h00.8m	23h48.5m	21h54.3m	18h19.3m
Declination (2000.0)	–20°06'	–11°44'	–24°08'	–27°03'	–3°24'	–3°57'	–2°04'	–13°15'	–18°49'

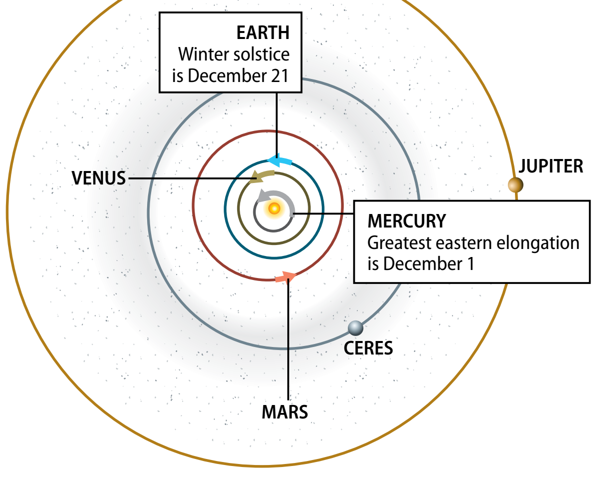
Jupiter's moons

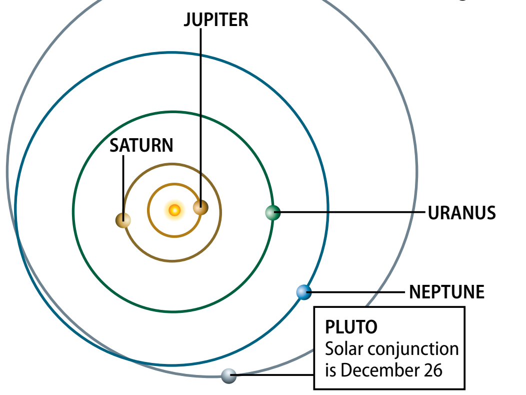
Dots display positions of Galilean satellites at 10 P.M. EST on the date shown.
South is at the top to match the view through a telescope.



The planets in their orbits

Arrows and dots show
planets' positions
during December.


EARTH
Winter solstice is December 21
VENUS
JUPITER
MERCURY
Greatest eastern elongation is December 1
CERES
MARS


JUPITER
SATURN
URANUS
NEPTUNE
PLUTO
Solar conjunction is December 26

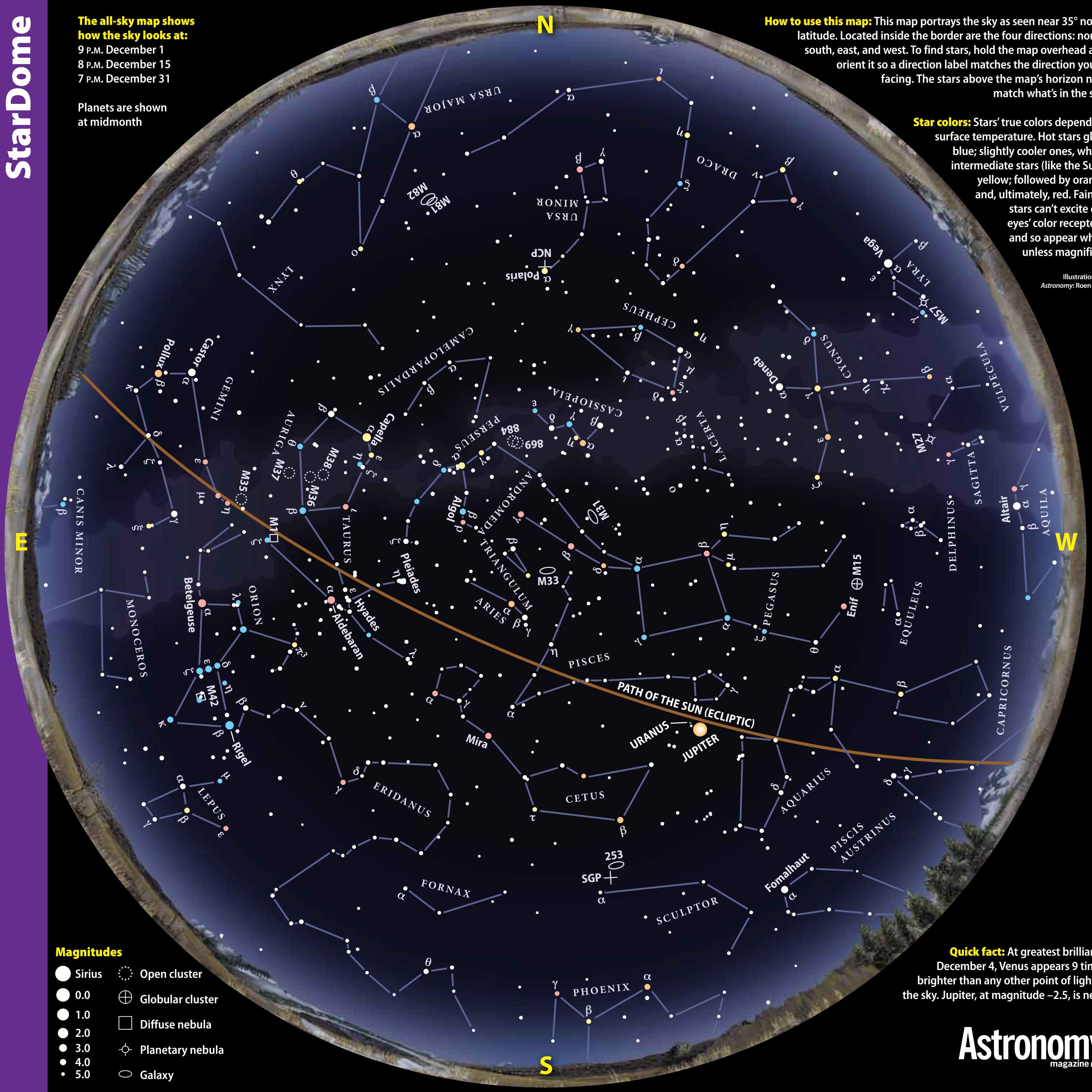
The all-sky map shows how the sky looks at:
9 P.M. December 1
8 P.M. December 15
7 P.M. December 31

Planets are shown at midmonth

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

Star colors: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white unless magnified.

Illustrations by *Astronomy*: Roen Kelly


N
E
W
S
URSA MAJOR
URSA MINOR
DRACO
LYRA
Vega
M57
CYGNUS
Deneb
CEPHEUS
NCP
Polaris
M81
M82
LYNX
CAMELOPARDALIS
CASSIOPEIA
LACERTA
VULPECULA
M27
SAGITTA
Altair
AQUILA
DELPHINUS
EQUULEUS
M15
Enif
PEGASUS
ANDROMEDA
M31
PERSEUS
869
884
Algol
TRIANGULUM
M33
ARIES
Pleiades
AURIGA
Capella
M36
M37
M38
GEMINI
Castor
Pollux
M35
M1
TAURUS
Hyades
Aldebaran
ORION
Betelgeuse
M42
Rigel
CANIS MINOR
MONOCEROS
LEPUS
ERIDANUS
Mira
CETUS
PISCES
PATH OF THE SUN (ECLIPTIC)
URANUS
JUPITER
AQUARIUS
CAPRICORNUS
PISCIS AUSTRINUS
Fomalhaut
SCULPTOR
FORNAX
SGP
253
PHOENIX

Magnitudes

- ● Sirius
- ● 0.0
- ● 1.0
- ● 2.0
- • 3.0
- • 4.0
- · 5.0

- ⁙ Open cluster
- ⊕ Globular cluster
- ☐ Diffuse nebula
- ⌖ Planetary nebula
- ⬭ Galaxy

Quick fact: At greatest brilliancy December 4, Venus appears 9 times brighter than any other point of light in the sky. Jupiter, at magnitude –2.5, is next.

Astronomy magazine

December 2010

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

Calendar of events

1 Mercury is at greatest eastern elongation (21°), 11 A.M. EST

The Moon passes 8° south of Saturn, 1 P.M. EST

2 The Moon passes 6° south of Venus, 4 P.M. EST

4 Venus is at greatest brilliancy (magnitude –4.9), 5 A.M. EST

5 New Moon occurs at 12:36 P.M. EST

6 Uranus is stationary, 5 A.M. EST

7 The Moon passes 1.8° north of Mercury, 4 A.M. EST

8 Asteroid Psyche is at opposition, 9 P.M. EST

10 Mercury is stationary, 5 A.M. EST

11 The Moon passes 5° north of Neptune, 10 A.M. EST

13 The Moon is at apogee (251,286 miles from Earth), 3:34 A.M. EST

First Quarter Moon occurs at 8:59 A.M. EST

The Moon passes 7° north of Jupiter, 9 P.M. EST

14 The Moon passes 7° north of Uranus, 1 A.M. EST

Geminid meteor shower peaks

19 Mercury is in inferior conjunction, 8 P.M. EST

21 Full Moon occurs at 3:13 A.M. EST

Winter solstice occurs at 6:38 P.M. EST

Special observing date

21 Observers across North America will witness the first total lunar eclipse since February 2008.

22 Asteroid Pallas is in conjunction with the Sun, noon EST

25 The Moon is at perigee (228,953 miles from Earth), 7:16 A.M. EST

26 Pluto is in conjunction with the Sun, 8 P.M. EST

27 Last Quarter Moon occurs at 11:18 P.M. EST

28 The Moon passes 8° south of Saturn, 10 P.M. EST

30 Mercury is stationary, 3 A.M. EST

31 The Moon passes 7° south of Venus, 11 A.M. EST

See tonight's sky in Astronomy.com's STARDOME

Astronomy magazine

Sky Guide 2011

By Martin Ratcliffe
and Richard Talcott

Two total lunar eclipses grace our skies this year — in June and December. The Moon likely will take on an orange-red hue during totality. Marc Pinter-Krainer

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II Dec. 2010 Venus brightest before dawn
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IV Feb. 2011 Watch Epsilon Aurigae return to view
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VII May 2011 A spectacular predawn meeting
VIII June 2011 The Moon takes a bite from the Sun
IX July 2011 The dawn of a new era for Vesta
X Aug. 2011 Distant giants on the prowl
XI Sept. 2011 Venus returns to the evening sky
XII Oct. 2011 Jupiter reigns all night long
XIII Nov. 2011 A Lion purrs softly
XIV Dec. 2011 Taking a dip in Earth's shadow
XV Jan. 2012 A winter comet treat
XVI 2012 Preview Looking ahead to next year

Martin Ratcliffe *provides professional planetarium development for Sky-Skan, Inc.* **Richard Talcott** *is a senior editor of* Astronomy *magazine.*

A supplement to *Astronomy* magazine

2010
December

S	M	T	W	T	F	S
			1	2	3	4
○	6	7	8	9	10	11
12	◑	14	15	16	17	18
19	20	●	22	23	24	25
26	◐	28	29	30	31	

1	Mercury is at greatest eastern elongation (21°), 11 A.M. EST	👁 ∞ 🔭
	The Moon passes 8° south of Saturn, 1 P.M. EST	👁 ∞
2	The Moon passes 6° south of Venus, 4 P.M. EST	👁 ∞
4	Venus is at greatest brilliancy, 5 A.M. EST	👁 ∞ 🔭
7	The Moon passes 1.8° north of Mercury, 4 A.M. EST	👁 ∞
13	The Moon passes 7° north of Jupiter, 9 P.M. EST	👁 ∞
14	The Moon passes 7° north of Uranus, 1 A.M. EST	∞
	Geminid meteor shower peaks	👁
19	Mercury is in inferior conjunction, 8 P.M. EST	
21	Total lunar eclipse, 3 A.M. EST	👁 ∞ 🔭
	Solstice (northern winter/southern summer begins), 7 P.M. EST	👁
28	The Moon passes 8° south of Saturn, 10 P.M. EST	👁 ∞
31	The Moon passes 7° south of Venus, 11 A.M. EST	👁 ∞

👁 Events that can be viewed with **the naked eye**

∞ Events that can be viewed with **binoculars**

🔭 Events that can be viewed with a **telescope**

Venus brightest before dawn

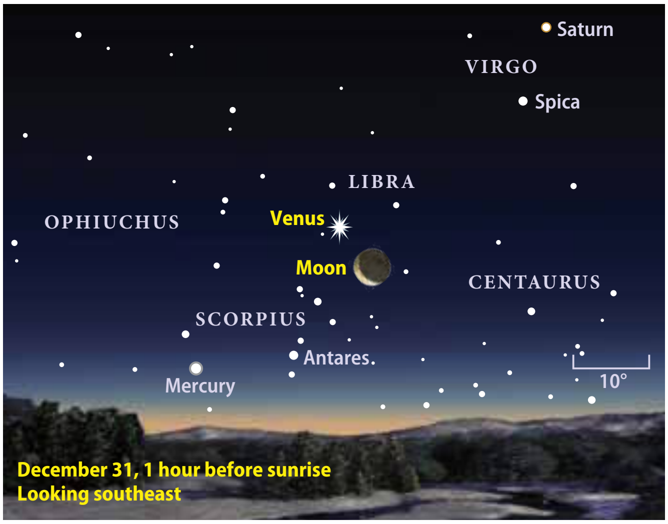
Rick Stankiewicz

A crescent Moon passes Venus twice this month, on the 2nd and 31st. The two bright objects will make a stunning pair in the predawn sky.

If you head outside any morning this month, a beacon in the southeastern sky will draw your eyes. This is Venus, and it appears brighter in early December than it has since February 2006. Gleaming at magnitude –4.9, it appears 25 times brighter than Sirius, the night sky's brightest star.

The planet reaches greatest brilliancy December 4, when it rises more than 3 hours before the Sun and lies 25° high an hour before sunrise. Although Venus dims slowly thereafter, it remains the "star" of these cold mornings throughout December and well into 2011. It will lie farthest from the Sun at greatest western elongation January 8.

In early December, Venus shares the southeastern sky with two 1st-magnitude objects: golden-colored Saturn and blue-white Spica. Spica, the brightest star in the constellation Virgo, lies to Venus' upper right, and Saturn appears almost directly above Spica. Venus moves quickly eastward relative to the background stars, however, and leaves Virgo for neighboring Libra in mid-December. By the end of the month, Venus is approaching 1st-magnitude Antares, the ruddy heart of the constellation Scorpius. (The planet will pass north of this star in mid-January.)



The Moon ends the year next to brilliant Venus. Look for the two in the southeast about an hour before sunrise. *Astronomy*: Roen Kelly

Try as they might, none of these 1st-magnitude objects can compare with Venus. Its only rival for predawn dominance comes when the Moon passes near. Luckily, observers have two opportunities this month to witness such beautiful conjunctions. On December 2, a waning crescent Moon passes to Venus' lower right. The two return to similar positions on the 31st. It's a thrill to see the night sky's two brightest objects come together, so be sure to set your alarm for these mornings.

Unlike the Moon, Venus shines brightest when it shows a crescent phase. The planet more than compensates for its smaller percent of illumination by sporting a larger disk. You can track Venus' changing appearance easily through a small telescope. On December 1, Venus spans 42" and appears 24 percent illuminated. By the 31st, the planet's disk measures 27" across and shows a 45-percent-lit phase.

A meteor bonanza for early 2011

Prospects appear excellent for this year's Quadrantid meteor shower. The peak of activity arrives the night of January 3/4, which coincides with New Moon. If the weather cooperates (a big if this time of year), and you observe far from artificial lights, you could see up to 100 meteors per hour. No other 2011 meteor shower will match these nearly ideal conditions.

The Quadrantids rise quickly to a peak and then fade away just as fast. Compared with August's Perseid meteor shower, whose numbers stay above 50 percent of maximum intensity for about 2 days, the Quadrantids manage this intensity level for only several hours.

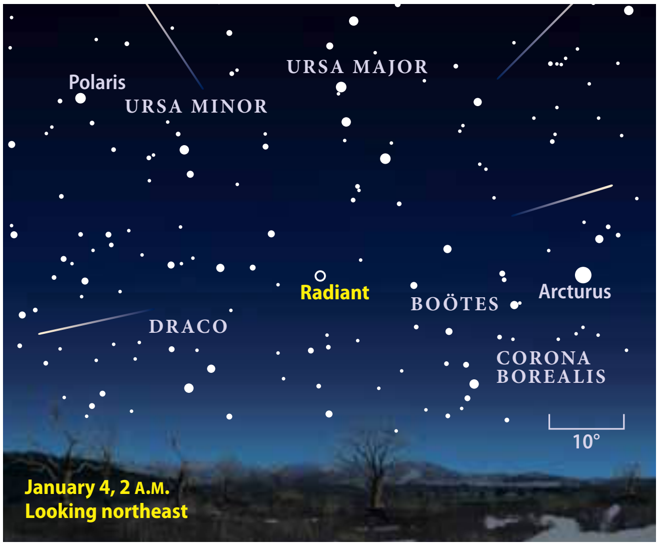
The meteors that belong to a particular shower arise when Earth passes through debris ejected by a periodic comet. The Quadrantids reach such a sharp peak because the debris trail laid down by its parent comet is unusually narrow. (Oddly enough, this "comet" goes by an asteroid designation: 2003 EH$_1$. Astronomers think it is the rocky core of a comet that ran out of ice and so is no longer active.)

This narrow peak means observers in only a limited range of geographic longitudes get to see the shower at its best. Astronomers predict the peak will arrive at around 8 P.M. EST January 3 (1h UT January 4), but this timing could be off by a couple of hours. This means the best views likely will come from Europe, although those in eastern North America should keep alert as well.

The radiant — the point from which the meteors appear to originate — lies in the northern part of Boötes the Herdsman, although the shower gets its name from the now-defunct constellation Quadrans Muralis. Around 1775, German astronomer Johann Bode proposed the latter name for this region. The International Astronomical Union removed it from the heavens in 1928 when the organization adopted the current list of 88 constellations.

The Quadrantid radiant lies near the northeastern horizon until late evening, when it starts to climb rapidly. It stands about one-third of the way to the zenith by 2 A.M. local time and appears halfway up the sky by 4 A.M.

Bright flashes of light characterize the Quadrantid meteor shower. In this photo, a Quadrantid passes near the Southern Cross. Frankie Lucena



Quadrantid meteors will streak across the sky in January's first week. The prolific shower should be the year's meteor highlight because it peaks around New Moon. *Astronomy*: Roen Kelly

2011 January

S	M	T	W	T	F	S
						1
2	3	○	5	6	7	8
9	10	11	◑	13	14	15
16	17	18	●	20	21	22
23	24	25	◐	27	28	29
30	31					

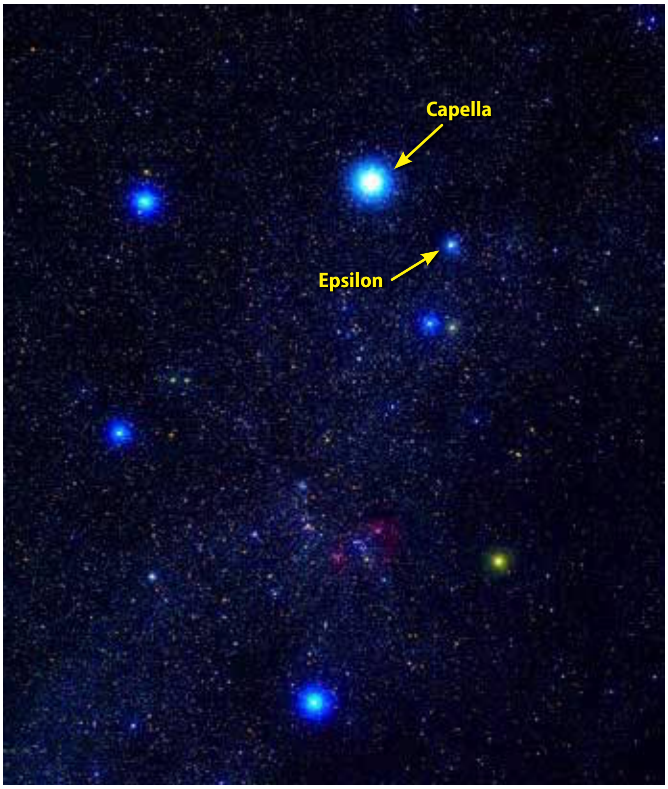
2	Jupiter passes 0.6° south of Uranus, 9 A.M. EST
	The Moon passes 4° south of Mercury, 10 A.M. EST
3	Quadrantid meteor shower peaks
4	Partial solar eclipse, 4 A.M. EST
7	The Moon passes 5° north of Neptune, 7 P.M. EST
8	Venus is at greatest western elongation (47°), 11 A.M. EST
9	Mercury is at greatest western elongation (23°), 10 A.M. EST
10	The Moon passes 7° north of Uranus, 10 A.M. EST
	The Moon passes 7° north of Jupiter, noon EST
15	Venus passes 8° north of Antares, 5 P.M. EST
25	The Moon passes 8° south of Saturn, 5 A.M. EST
29	The Moon passes 3° south of Venus, 11 P.M. EST
30	Asteroid Ceres is in conjunction with the Sun, 8 P.M. EST

2011 February

S	M	T	W	T	F	S
		1	○	3	4	5
6	7	8	9	10	◑	12
13	14	15	16	17	●	19
20	21	22	23	◐	25	26
27	28					

1	The Moon passes 4° north of Mercury, 1 P.M. EST	👁 🔭
4	Mars is in conjunction with the Sun, noon EST	
6	The Moon passes 6° north of Uranus, 7 P.M. EST	🔭
7	The Moon passes 7° north of Jupiter, 5 A.M. EST	👁 🔭
17	Neptune is in conjunction with the Sun, 5 A.M. EST	
21	The Moon passes 8° south of Saturn, noon EST	👁 🔭
25	Mercury is in superior conjunction, 4 A.M. EST	
28	The Moon passes 1.6° north of Venus, 11 P.M. EST	👁 🔭

Watch Epsilon Aurigae return to view



Epsilon (ε) Aurigae recovers from its 2-year-long eclipse this year. Expect it to shine near 4th magnitude in early 2011 but reach 3rd magnitude by midyear. Bill and Sally Fletcher

One of the sky's most mysterious stars has spent the past 18 months at less than full brightness. Epsilon (ε) Aurigae typically shines at magnitude 3.0, yet once every 27 years, it dims by more than half to magnitude 3.8. Epsilon bottomed out last August and has since started to recover. It should return to full brightness in the first half of 2011.

You can estimate Epsilon's brightness with your naked eyes. First, you need to find it — an easy task because it lies just southwest of Capella, Auriga's brightest star and the sixth-brightest star in the night sky. This region passes nearly overhead on February evenings. Estimating a star's brightness involves comparing it with the brightnesses of nearby stars with similar magnitudes. For details on charting Epsilon, check out the Citizen Sky website at www.citizensky.org.

Astronomers long suspected that Epsilon is an eclipsing binary. In these systems, two stars orbit each other in a plane that lies along our line of sight. When the dimmer companion passes in front of the brighter primary, we see the system's total light drop. But astronomers had never seen another eclipsing binary where the dimming lasted 2 years.

Detailed observations in 2009 and 2010 helped clarify what is going on. The system's luminary is an F-type giant star with a mass somewhere between 1 and 4 times that of the Sun. The companion is a 6-solar-mass B-type star embedded in a cool disk of dust that spans some 8 times the average Earth-Sun distance.

The disk inclines just a couple of degrees to our line of sight, rendering the B star practically invisible most of the time. Recent observations show that the F star is near the end of its life and has started ejecting its outer envelope. This material condenses into dust, which the B star ultimately captures.

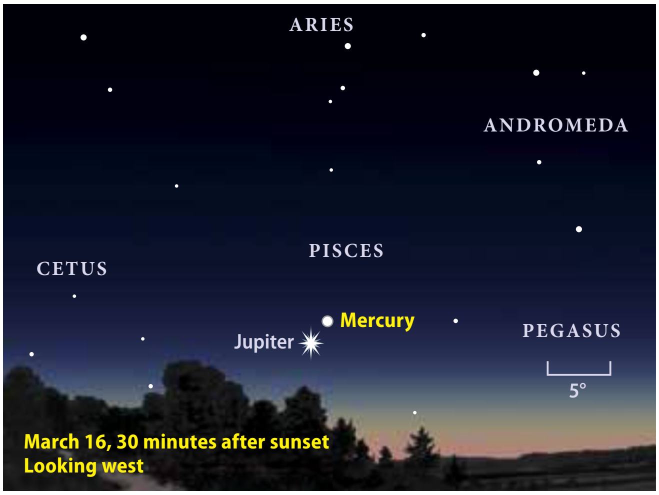
Still, scientists have much to learn about Epsilon Aurigae. As Arne Henden, director of the American Association of Variable Star Observers, notes, "Watching half of this peculiar eclipse is like seeing the front half of an elephant and theorizing what the back half looks like."

Henden wonders whether the dust disk is symmetrical, if the eclipse will end as predicted, and whether we will see short-term brightness fluctuations caused by pulsations of the F star or by lumps in the dusty disk. "Only further observations will solve these mysteries," says Henden.

Catch Mercury at its own game

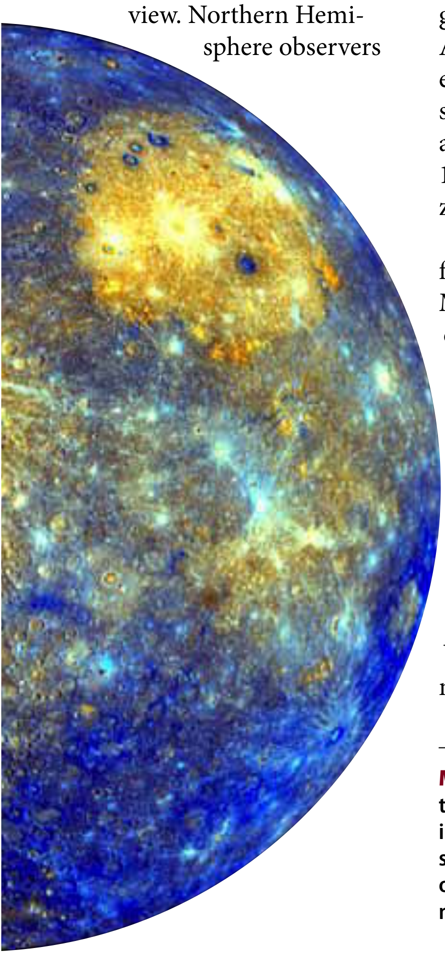
The innermost planet plays hide and seek with us approximately every 2 months. As Mercury's orbit carries it east of the Sun, it climbs higher into the evening sky. But as soon as it reaches a decent altitude, it quickly drops back toward the Sun and becomes lost in the glare. Two months later, Mercury appears west of the Sun before dawn, tempting us with its increasing separation. But it's destined to repeat its evening act, remaining on view for a few weeks before disappearing into the Sun's bright glow.

You have to be as crafty as Mercury to catch a good view. Northern Hemisphere observers have their best chance of 2011 when Mercury reaches greatest elongation March 22. Although it then lies just 19° east of the Sun, most of that separation translates into altitude. The planet appears 12° above the western horizon 30 minutes after sunset.



Locate Mercury this month by using brilliant Jupiter as a guide. The two planets appear closest the evening of March 16. *Astronomy*: Roen Kelly

This apparition benefits from the presence of Jupiter. Mercury passes just 2° north of Jupiter March 16. That evening, Jupiter shines at magnitude –2.1 and Mercury at magnitude –0.9. Mercury fades some by the time it reaches greatest elongation the following week. (The planet always appears brighter at the start of evening appearances and brighter toward the end of morning appearances.)



Mercury glows in false color in this 2008 MESSENGER spacecraft image. Expect plenty more great shots as the NASA probe starts to orbit the innermost planet this month. NASA/JHUAPL/CIW

Mercury also appears in the evening sky in late July and mid-November, although at significantly lower altitudes. During November, brilliant Venus stays within a couple of degrees of Mercury for more than a week.

Some observers prefer to wake up early to view the morning sky. Those early risers can find Mercury in early January, early May, early September, and late December. September offers perhaps the best opportunity because the planet rises more than an hour before sunrise and appears in the vicinity of Leo's brightest star, Regulus. On September 9, the two lie just 0.7° apart.

Although Mercury's altitude won't be as high in May, don't pass on this chance to view the planet. Beginning May 4, Mercury remains within 2° of Venus for more than 2 weeks, and both Jupiter and Mars lie nearby. See May's entry for more details.

2011
March

S	M	T	W	T	F	S
		1	2	3	○	5
6	7	8	9	10	11	◑
13	14	15	16	17	18	●
20	21	22	23	24	25	◐
27	28	29	30	31		

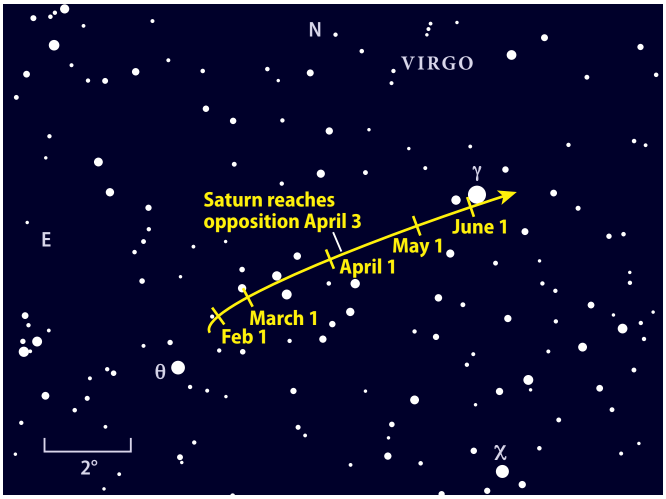
6	The Moon passes 7° north of Jupiter, midnight EST
12	Asteroid Juno is at opposition, 5 A.M. EST
16	Mercury passes 2° north of Jupiter, 1 P.M. EDT
20	Equinox (northern spring/southern autumn begins), 7 P.M. EDT
	The Moon passes 8° south of Saturn, 8 P.M. EDT
21	Uranus is in conjunction with the Sun, 8 A.M. EDT
22	Mercury is at greatest eastern elongation (19°), 9 P.M. EDT
26	Venus passes 0.2° south of Neptune, 9 P.M. EDT
30	The Moon passes 5° north of Neptune, 10 P.M. EDT
31	The Moon passes 6° north of Venus, 9 A.M. EDT

2011
April

S	M	T	W	T	F	S
					1	2
○	4	5	6	7	8	9
10	◑	12	13	14	15	16
●	18	19	20	21	22	23
◐	25	26	27	28	29	30

3	Saturn is at opposition, 8 P.M. EDT
6	Jupiter is in conjunction with the Sun, 11 A.M. EDT
9	Mercury is in inferior conjunction, 4 P.M. EDT
17	The Moon passes 8° south of Saturn, 4 A.M. EDT
19	Mercury passes 0.8° north of Mars, 4 A.M. EDT
22	Venus passes 0.9° south of Uranus, 3 P.M. EDT
	Lyrid meteor shower peaks
27	The Moon passes 6° north of Neptune, 6 A.M. EDT
29	The Moon passes 6° north of Uranus, midnight EDT
30	The Moon passes 7° north of Venus, 7 P.M. EDT

Saturn's rings open wide



Saturn spends 2011 among the background stars of central Virgo. The ringed planet shines noticeably brighter than 1st-magnitude Spica, the constellation's brightest star. *Astronomy*: Roen Kelly

Everyone's favorite telescopic target, Saturn, appears at its best for the year in April. The ringed planet reaches opposition and peak visibility April 3. For any outer planet, opposition marks the moment when it lies opposite the Sun in our sky and remains visible all night. The planet also shines brightest and appears biggest through a telescope around this time.

Saturn shines at magnitude 0.4 at opposition. This makes it the brightest object within the boundaries of Virgo, Saturn's home constellation all year.

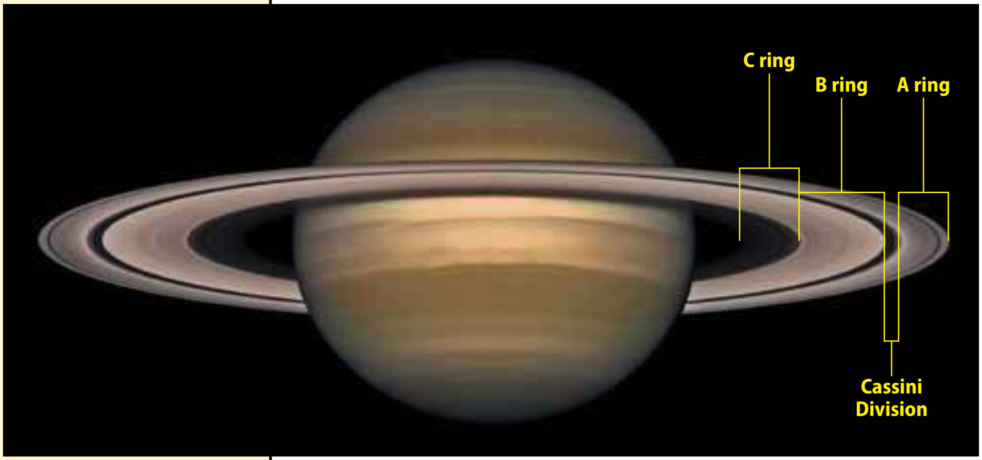
The ringed planet rises shortly after midnight at the beginning of January, when it appears about halfway between Spica, Virgo's brightest star at magnitude 1.0, and 3rd-magnitude Gamma (γ) Virginis. Saturn's motion against the background stars carries it toward Gamma all spring. By June, the two stand just 0.3° apart. The planet disappears in the evening twilight in September, then returns to view before dawn in late October.

At opposition, Saturn's disk measures 19" across and its rings span 44". The disk appears bland through a telescope, particularly in comparison to Jupiter's dramatic belts and zones. Nevertheless, careful observers will notice subtle brightness differences across the disk.

There's nothing subtle about Saturn's rings. At opposition this year, they tilt 9° to our line of sight. That's 3 times greater than at opposition in 2010, so our view has improved dramatically. And by year's end, the rings' tilt increases to 15°.

A telescope easily shows Saturn's two brightest rings. The B ring is broader and brighter and lies inside the outermost A ring. The dark Cassini Division, a region largely devoid of material, separates these two. A third main ring shows up under good viewing conditions. The semi-transparent C ring lies closest to Saturn.

A small telescope also reveals several moons. Eighth-magnitude Titan shows up through any scope — it appears as the brightest "star" close to Saturn. Rhea, Tethys, and Dione all glow at 10th magnitude and are almost as easy to see.



NASA/ESA/Hubble Heritage Team (STScI/AURA)

Saturn's rings open wider this year. At opposition in April, the rings tilt 9° to our line of sight and appear spectacular through any telescope.

A spectacular predawn meeting

Sparkling Venus (left) and Jupiter passed near each other before dawn in early February 2008. The pair re-create this early-morning scene during May's second week. Tunç Tezel

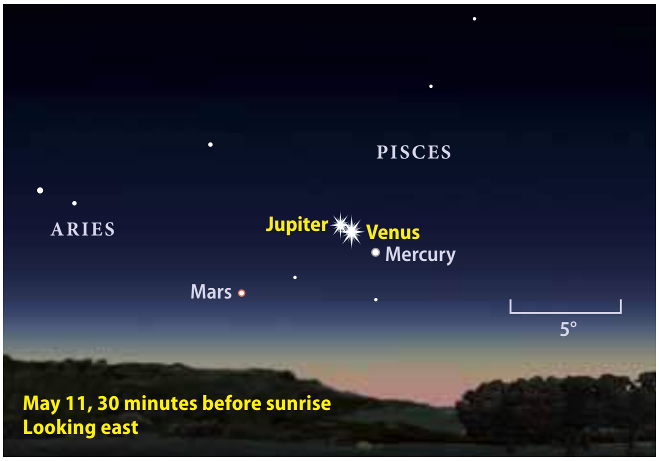
The two brightest planets make a stunning pair when they meet in the morning sky May 11. Venus and Jupiter then lie just 34' apart, a shade more than 1 Full Moon-width. They rise together an hour before sunrise. Venus shines at magnitude –3.8 and Jupiter at magnitude –2.1, which also makes them the two brightest objects in the sky.

Two more challenging planets lie in the same region. That morning, Mercury appears 1.5° south of Venus and Mars is 5° east of Jupiter. However, Mercury glows at magnitude 0.2 and Mars at magnitude 1.3, so they will be hard to see in the brightening twilight. Binoculars should bring them out of the glow.

A series of nice conjunctions begins April 30. That morning, a waning crescent Moon rises around 4:30 local daylight time followed by Venus some 35 minutes later. Look for Venus directly below the Moon in the twilight glow. Mercury rises about 12 minutes after Venus. (Exact times depend on your latitude.) Viewers with a clear eastern horizon might spot the innermost planet, which glows at magnitude 0.9, some 4° due east of Venus.

On April 30, Jupiter rises 25 minutes after Venus and only 40 minutes before the Sun. Given its brilliance, Jupiter may show up faintly in the advancing twilight. Mars, on the other hand, a Full Moon-width to Jupiter's west, will be a true challenge. Once again, binoculars will help you spot the fainter planets. On May 1, a crescent Moon even thinner than the one a morning earlier lies directly above the Jupiter-Mars pair.

During the next 10 days, Jupiter pulls away from Mars and rises to meet Venus and Mercury. The pinnacle will be the May 11 event. Following this dramatic conjunction, the orbital motions of Mercury and Venus cause them to fall back toward the Sun's glow, with Mercury disappearing from view first. Jupiter continues to rise earlier. On May 29, it will meet a crescent Moon fatter than the one next to it May 1. On the 31st, see if you can find the 28-day-old Moon and Venus some 5° to its right.



Astronomy: Roen Kelly

Venus joins Jupiter in the eastern sky before dawn May 11. The two brightest planets lie one Full Moon-width apart in the twilight glow.

2011 May

S	M	T	W	T	F	S
1	2	○	4	5	6	7
8	9	◑	11	12	13	14
15	16	●	18	19	20	21
22	23	◐	25	26	27	28
29	30	31				

1	The Moon passes 8° north of Mercury, 3 A.M. EDT
	Mars passes 0.4° north of Jupiter, 7 A.M. EDT
	The Moon passes 6° north of Jupiter, 3 P.M. EDT
	The Moon passes 6° north of Mars, 4 P.M. EDT
6	Eta Aquarid meteor shower peaks
7	Mercury is at greatest western elongation (27°), 3 P.M. EDT
10	Mercury passes 2° south of Jupiter, 7 P.M. EDT
11	Venus passes 0.6° south of Jupiter, 5 A.M. EDT
14	The Moon passes 8° south of Saturn, 11 A.M. EDT
19	Mercury passes 2° south of Mars, 9 P.M. EDT
22	Venus passes 1.1° south of Mars, 11 A.M. EDT
24	The Moon passes 6° north of Neptune, 2 P.M. EDT
27	The Moon passes 6° north of Uranus, 9 A.M. EDT
29	The Moon passes 6° north of Jupiter, 11 A.M. EDT
30	The Moon passes 4° north of Mars, 4 P.M. EDT
	The Moon passes 4° north of Venus, midnight EDT

2011
June

S	M	T	W	T	F	S
			○	2	3	4
5	6	7	◑	9	10	11
12	13	14	●	16	17	18
19	20	21	22	◐	24	25
26	27	28	29	30		

1 Partial solar eclipse, 5 P.M. EDT

10 The Moon passes 8° south of Saturn, 5 P.M. EDT

12 Mercury is in superior conjunction, 8 P.M. EDT

15 Total lunar eclipse, 4 P.M. EDT

18 Venus passes 5° north of Aldebaran, 4 A.M. EDT

20 The Moon passes 6° north of Neptune, 10 P.M. EDT

21 Solstice (northern summer/southern winter begins), 1 P.M. EDT

23 The Moon passes 6° north of Uranus, 7 P.M. EDT

26 The Moon passes 5° north of Jupiter, 5 A.M. EDT

28 Pluto is at opposition, 1 A.M. EDT

The Moon passes 1.7° north of Mars, 3 P.M. EDT

Mercury passes 5° south of Pollux, 6 P.M. EDT

The Moon takes a bite from the Sun

A crescent Sun shines through clouds in this view of the partial phases of the July 22, 2009, solar eclipse. The Sun and Moon create four solar eclipses this year, all of them partials. Timothy Boyle

This is a banner year for eclipses. Six occur during 2011: four partial eclipses of the Sun and two total eclipses of the Moon. The best solar eclipse for North American observers comes June 1, when people in parts of Alaska and Canada can see the Moon cover up to about 20 percent of the Sun.

Eclipses occur when two things happen simultaneously. First, the line of nodes — the line that connects the two points on the Moon's orbit that intersect Earth's orbit around the Sun — needs to point in the Sun's general direction. Second, the Moon has to be at either its new or full phase. Solar eclipses occur at New Moon and lunar eclipses at Full Moon.

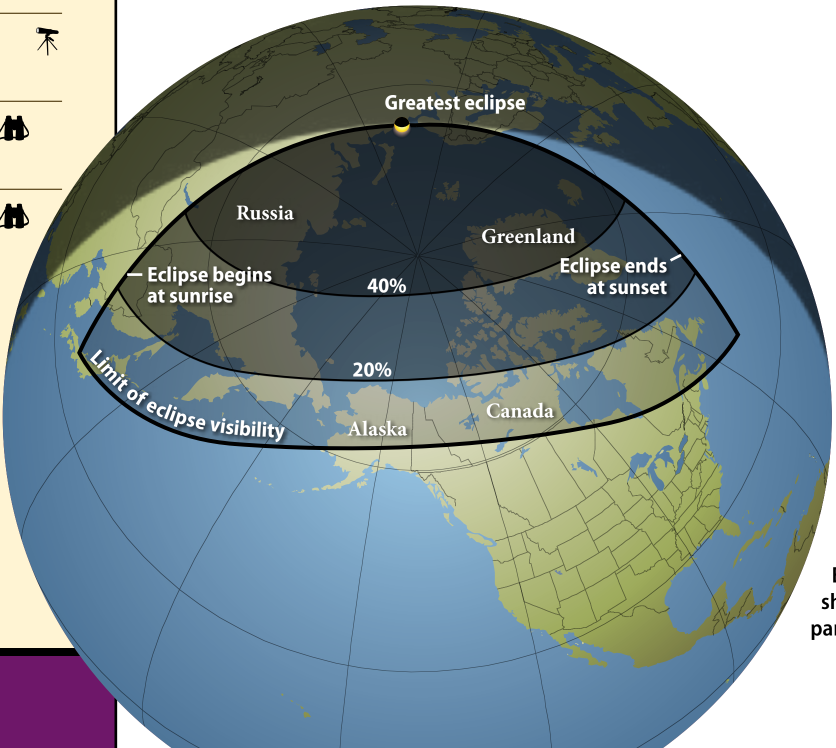
The geometry that causes eclipses repeats at slightly less than 6-month intervals. That's why we have eclipses this year in January, June/July, and November/December.

Viewers across the Arctic Ocean and the northern parts of its neighboring continents can see June 1's partial solar eclipse. Maximum eclipse occurs along the northern coast of Russia, where the Moon blocks 60 percent of the Sun from view. Those across the northern tip of Europe, northeastern Asia, the northern two-thirds of Alaska, and much of northern and eastern Canada will see less of the Sun eclipsed.

This year's other good solar eclipse occurs January 4. Residents in most of Europe, northern Africa, the Middle East, and western Asia can view this event. Maximum eclipse occurs in northern Europe, where the Moon covers 86 percent of the Sun. The Moon takes a smaller bite from locations farther south.

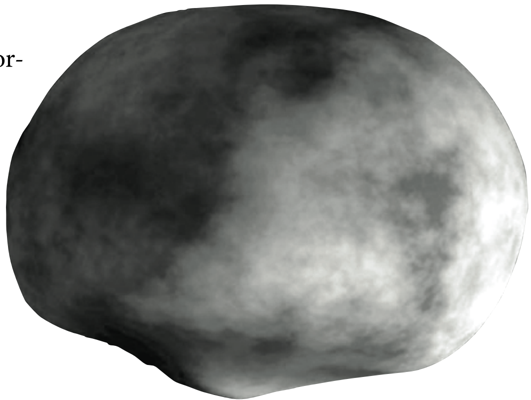
The year's other two solar eclipses come July 1 and November 25. Both favor observers in the Antarctic and feature the Moon blocking less than 10 percent of the Sun. Because all of this year's solar eclipses are partials, you'll need eye protection to view them safely.

For details on 2011's two total lunar eclipses, see December's entry.



The Moon covers part of the Sun June 1. Residents of northern Eurasia and northern North America should have the best views of this partial eclipse. *Astronomy*: Roen Kelly

The dawn of a new era for Vesta



This computer model of Vesta, based on Hubble Space Telescope images, is the best view ever of the asteroid. That will change this year when NASA's Dawn spacecraft orbits Vesta. Ben Zellner (Georgia Southern University)/Peter Thomas (Cornell University)/NASA

If all goes according to plan, scientists will get their first close-up views of a large main-belt asteroid this month. NASA's Dawn spacecraft will approach Vesta, the brightest asteroid, as the probe prepares to orbit the object in August. This unprecedented encounter closely coincides with Vesta's August 5 opposition. Around that time, Vesta will reach magnitude 5.6 — the brightest it's been in 4 years — bringing it within reach of naked eyes from a dark site. It will be an easy target through binoculars.

German astronomer Heinrich Olbers discovered Vesta in 1807. He also discovered Pallas 5 years earlier. So Olbers, most famous for asking why the sky is dark at night, found two of the first four asteroids. With a period of 3.63 years, Vesta orbits the Sun in less time than the other three.

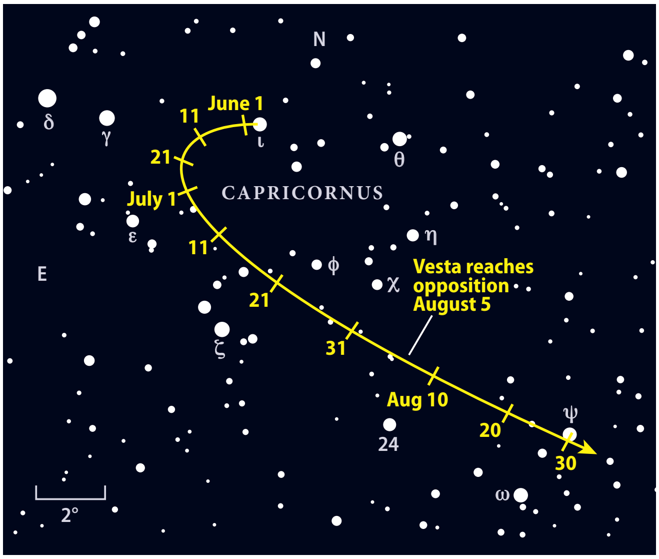
Vesta lies among the background stars of Capricornus the Sea Goat throughout summer. The easiest way to spot it, or any asteroid for that matter, is to see it move relative to nearby stars. A fine opportunity presents itself May 30, when Vesta lies 4' west of 4th-magnitude Iota (ι) Capricorni. The next night, the asteroid appears 7' east of the star. Vesta appears relatively faint in late May, glowing at magnitude 6.9.

By June 20, Vesta has brightened to magnitude 6.5 and lies in line with Delta (δ) and Gamma (γ) Cap. Just 2° separate these stars in northeastern Capricornus, making them easy to identify. If you need help, a gibbous Moon hangs 6° north of this pair. Vesta lies 2° west of Gamma.

Vesta heads south for the remainder of June, then turns toward the southwest in July. On the 19th, it stands as the fifth "star" in an elegant arc that begins with 4th-magnitude Zeta (ζ) Cap.

At opposition August 5, the asteroid lies approximately midway between Chi (χ) and 24 Cap. Vesta continues its trek across Capricornus, passing within 9' of the 4th-magnitude star Psi (ψ) Cap August 30.

Once Dawn arrives at Vesta, it will remain in orbit until May 2012. It then will fire its ion drive and head to Ceres, the largest asteroid, which it will reach in February 2015. Vesta is a rocky world and Ceres an icy body, so Dawn will investigate these differences. Ceres will reach opposition in southwestern Cetus September 16.



Vesta treks through Capricornus when it glows brightest in late July and early August. The 6th-magnitude asteroid will be easy to spot through binoculars. *Astronomy*: Roen Kelly

2011 July

S	M	T	W	T	F	S
					○	2
3	4	5	6	7	◑	9
10	11	12	13	14	●	16
17	18	19	20	21	22	◐
24	25	26	27	28	29	○
31						

1	Partial solar eclipse, 5 A.M. EDT
2	The Moon passes 5° south of Mercury, 10 P.M. EDT
6	Mars passes 5° north of Aldebaran, 3 A.M. EDT
7	The Moon passes 8° south of Saturn, midnight EDT
18	The Moon passes 6° north of Neptune, 6 A.M. EDT
20	Mercury is at greatest eastern elongation (27°), 1 A.M. EDT
21	The Moon passes 6° north of Uranus, 3 A.M. EDT
23	The Moon passes 5° north of Jupiter, 9 P.M. EDT
27	The Moon passes 0.5° south of Mars, 1 P.M. EDT
29	Asteroid Pallas is at opposition, 10 A.M. EDT

2011
August

S	M	T	W	T	F	S
	1	2	3	4	5	◑
7	8	9	10	11	12	●
14	15	16	17	18	19	20
◐	22	23	24	25	26	27
○	29	30	31			

1	The Moon passes 1.5° south of Mercury, 7 A.M. EDT
4	The Moon passes 8° south of Saturn, 8 A.M. EDT
5	Asteroid Vesta is at opposition, 6 A.M. EDT
13	Perseid meteor shower peaks
14	The Moon passes 6° north of Neptune, noon EDT
16	Venus is in superior conjunction, 8 A.M. EDT
	Mercury is in inferior conjunction, 9 P.M. EDT
17	The Moon passes 6° north of Uranus, 9 A.M. EDT
20	The Moon passes 5° north of Jupiter, 8 A.M. EDT
22	Neptune is at opposition, 7 P.M. EDT
25	The Moon passes 3° south of Mars, 10 A.M. EDT
27	The Moon passes 3° south of Mercury, 9 P.M. EDT
31	The Moon passes 7° south of Saturn, 7 P.M. EDT

Distant giants on the prowl

Neptune appears as a crescent in this view taken by the Voyager 2 spacecraft after it passed the planet in 1989. Unfortunately, no one on Earth can enjoy a similar perspective. NASA/JPL

Neptune passes a notable milestone this summer. On July 7, the most distant major planet completes its first orbit of the Sun since its discovery September 23, 1846. Neptune then lies in southwestern Aquarius, next to Iota (ι) Aquarii and near its position at discovery. Neptune, a planet 4 times the diameter of Earth, takes 164.8 years to orbit the Sun.

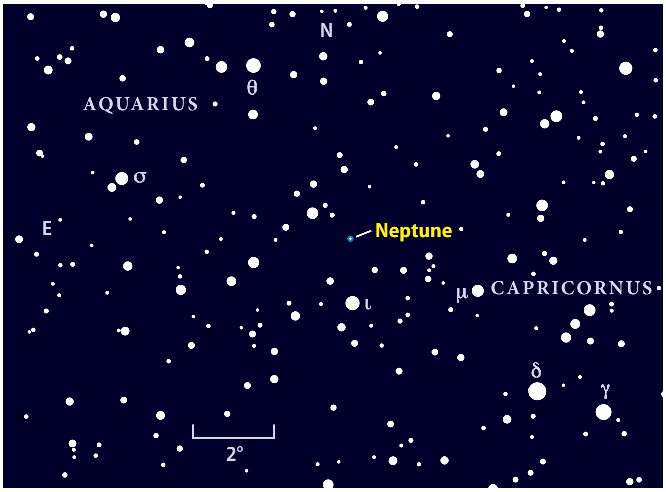
Neptune's discovery was a landmark in astronomical science. From theory alone, scientists calculated the planet's position by analyzing deviations found in the orbit of its inner neighbor, Uranus. Sir John Herschel recounted the discovery in his 1849 book, *Outlines of Astronomy*. He exclaimed that Neptune had been found, "*within a single degree* [his italics] of the place assigned by M. Leverrier's calculations … and within two and a half from that indicated by Mr. Adams." German astronomer Johann Galle first sighted Neptune through a 9-inch telescope at the Berlin Observatory.

The historical significance of Neptune's discovery makes August a fine month to rediscover the distant world, which reaches opposition and peak visibility August 22. Head outside and locate Iota Aquarii. On August 24, Neptune lies 1.6° due north of this 4th-magnitude star. The planet glows at magnitude 7.8 and shows up easily through 7x50 binoculars.

To confirm your sighting, target Neptune through a telescope. Although the planet lies 2.7 billion miles from Earth, it displays a 2.4"-diameter disk with a noticeable blue-gray color. Both the disk and its color verify that this is no star.

Neptune's sister planet, Uranus, reaches opposition September 25. Uranus lies one constellation east of Neptune, in a sparse section of Pisces the Fish. At magnitude 5.7, Uranus glows bright enough to spot with naked eyes from a dark site. The fact that no star of similar brightness lies within 3° of the planet makes the task even easier.

To locate Uranus, use the stars Alpheratz and Algenib, which form the eastern edge of the Great Square of Pegasus. These stars stand 14° apart; Uranus lies another 15° south of Algenib. The alignment works best in early September, but Uranus' slow motion means it holds pretty well all month. If you can't find the planet without optical aid, binoculars bring it easily into view. A telescope reveals Uranus' blue-green disk, which spans 3.7".

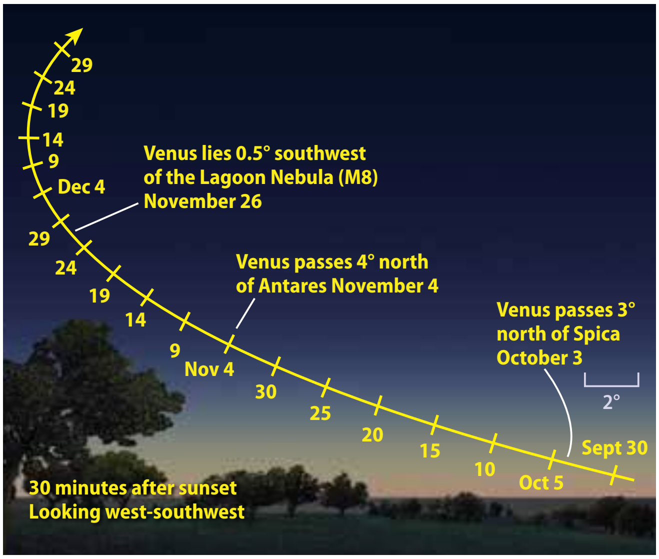


Neptune lurks in southwestern Aquarius this year, not far from where astronomer Johann Galle first spotted it 165 years ago. *Astronomy*: Roen Kelly

Venus returns to the evening sky

As September draws to a close, Venus pops into view low in the west after sunset. It won't be easy to spot — it sets barely 30 minutes after the Sun — but you should see it if you have clear, dry weather and an unobstructed horizon. The planet's brilliance (magnitude −3.9) helps it shine through the twilight glow.

Venus' reappearance heralds the start of an evening apparition that lasts into spring 2012. Along the way, the planet has a number of conjunctions worth viewing. On October 3, it passes 3° north of Spica, Virgo's brightest star. And on November 9, it passes 4° north of Antares, the brightest star in Scorpius.



Venus lies 0.5° southwest of the Lagoon Nebula (M8) November 26

Venus passes 4° north of Antares November 4

Venus passes 3° north of Spica October 3

30 minutes after sunset
Looking west-southwest

Venus returns to view after sunset in late September. Look for it low in the west about 30 minutes after sunset. *Astronomy*: Roen Kelly

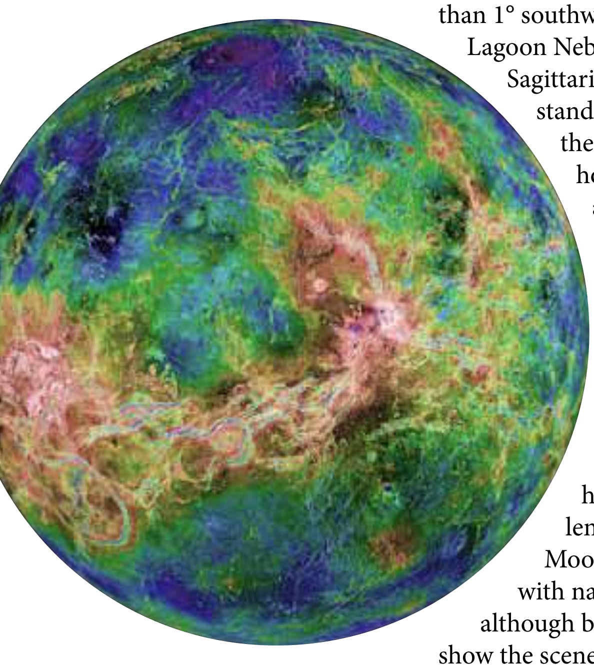
But the most intriguing event occurs November 26. That evening, Venus lies less than 1° southwest of the Lagoon Nebula (M8) in Sagittarius. The pair stands just 5° above the southwestern horizon 1 hour after sunset, while twilight paints the sky. And a thin crescent Moon lies 4° to Venus' right.

You should have no problem spotting the Moon and Venus with naked eyes, although binoculars show the scene best. To see the Lagoon, however, you'll need a clear sky, low humidity, and good optics.

Venus' visibility continues to improve through year's end. By December 31, the planet stands 15° high an hour after sunset. The view through a telescope changes in late 2011. In late September, it appears 10" across and almost fully lit. By New Year's Eve, the planet's diameter has grown to 13" while its phase has waned to a fat gibbous.

Venus appears higher in the sky before dawn early in 2011. It reaches its greatest elongation west of the Sun January 8. Through a telescope, it then shows a half-lit disk measuring 25" across.

The bright planet passes through northern Sagittarius in early February, when it has some more nice deep-sky conjunctions. On the 4th, it appears halfway between the open star cluster M23 and the Trifid Nebula (M20). And on the 11th, it stands halfway between the open cluster M25 and the globular cluster M22.



Volcanic highlands and deep basins highlight this mosaic of radar images captured by the Magellan spacecraft. To backyard observers, however, Venus reveals only clouds. NASA/JPL/USGS

2011 September

S	M	T	W	T	F	S
				1	2	3
◑	5	6	7	8	9	10
11	●	13	14	15	16	17
18	19	◐	21	22	23	24
25	26	○	28	29	30	

3	Mercury is at greatest western elongation (18°), 2 A.M. EDT	👁 ⚭ 🔭
8	Mercury passes 0.7° north of Regulus, 10 P.M. EDT	👁 ⚭ 🔭
9	Mars passes 6° south of Pollux, 10 P.M. EDT	👁 ⚭
10	The Moon passes 6° north of Neptune, 5 P.M. EDT	⚭
13	The Moon passes 6° north of Uranus, 2 P.M. EDT	⚭
16	Asteroid Ceres is at opposition, 1 P.M. EDT	⚭ 🔭
	The Moon passes 5° north of Jupiter, 2 P.M. EDT	👁 ⚭
23	The Moon passes 5° south of Mars, 4 A.M. EDT	👁 ⚭
	Equinox (northern autumn/southern spring begins), 5 A.M. EDT	👁
25	Uranus is at opposition, 8 P.M. EDT	👁 ⚭ 🔭
28	Mercury is in superior conjunction, 4 P.M. EDT	

2011
October

S	M	T	W	T	F	S
						1
2	🌓	4	5	6	7	8
9	10	🌕	12	13	14	15
16	17	18	🌗	20	21	22
23	24	25	🌑	27	28	29
30	31					

3 Venus passes 3° north of Spica, 8 A.M. EDT

7 The Moon passes 6° north of Neptune, 10 P.M. EDT

10 The Moon passes 6° north of Uranus, 6 P.M. EDT

13 The Moon passes 5° north of Jupiter, 4 P.M. EDT

Saturn is in conjunction with the Sun, 5 P.M. EDT

21 Orionid meteor shower peaks

The Moon passes 6° south of Mars, 8 P.M. EDT

22 Asteroid Juno is in conjunction with the Sun, 9 P.M. EDT

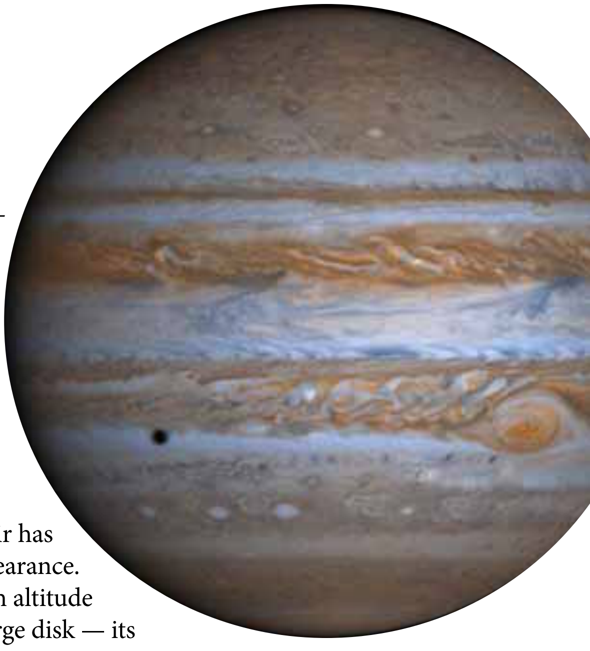
27 The Moon passes 0.2° south of Mercury, 10 P.M. EDT

28 The Moon passes 1.8° south of Venus, 1 A.M. EDT

Jupiter is at opposition, 10 P.M. EDT

31 Saturn passes 5° north of Spica, 1 A.M. EDT

Jupiter reigns all night long



Jupiter's dynamic atmosphere and the shadow of its moon Europa highlight this image returned from the Cassini spacecraft in early December 2000. NASA/JPL/SSI

Although Saturn would win any planetary beauty contest, Jupiter likely would triumph in a competition for the most dramatic planet. Jupiter's atmosphere is constantly on the move, nearly guaranteeing a different look each time you observe it. The best time to view any planet through a telescope is around opposition, when it appears largest and lies highest in the sky around local midnight. This year, Jupiter's opposition occurs October 28.

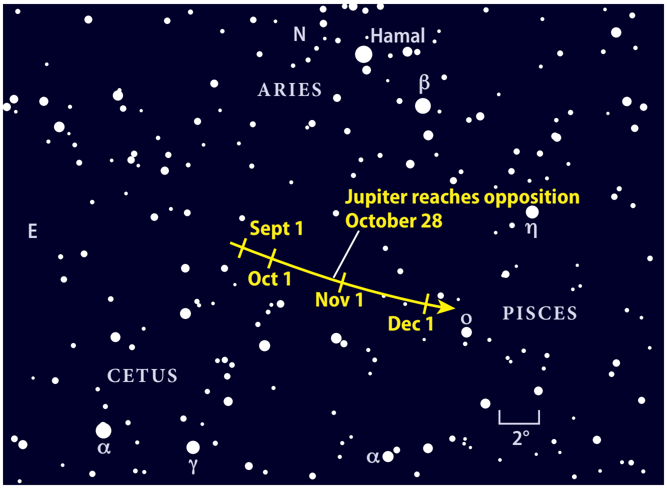
The giant planet then dominates the constellation Aries the Ram. It shines at magnitude –2.9, 100 times brighter than Aries' brightest star, Hamal (Alpha [α] Arietis). It appears dazzling in the eastern sky during twilight and grows even more prominent as it climbs high in a dark sky.

For the past half-dozen years, Jupiter has reached opposition while located south of the celestial equator. It passed through the constellations Libra, Ophiuchus, Sagittarius, Capricornus, Aquarius, and, last year, Pisces. For observers at mid-northern latitudes, this meant Jupiter did not lie particularly high in the sky. But Jupiter crosses the celestial equator heading northward this February. By opposition in October, it lies 12° north of the equator. This places Jupiter more than 60° above the southern horizon at local midnight in October.

The higher altitude has a profound effect on images of Jupiter seen through a telescope. The planet's light passes through much less of Earth's atmosphere than it has in recent years, noticeably reducing the blurring effects that turbulent air has on Jupiter's appearance. Couple this high altitude with Jupiter's large disk — its equatorial diameter reaches 50" at opposition — and you have the potential for stunning views.

Just what Jupiter will look like is a bit up in the air. The giant planet looked noticeably strange to regular observers during most of 2010. The two dark equatorial belts that normally straddle the jovian equator were reduced to just one dark band. The South Equatorial Belt turned a rather inconspicuous gray, and the Great Red Spot, which had been rather subdued compared with the usually dark belt, stood out.

By the time you read this, the second belt may have returned or it may still be gray. Either way, Jupiter should offer plenty of excitement to observers in 2011.



Jupiter shines big and bright in October when it reaches opposition and peak visibility among the background stars of Aries. *Astronomy*: Roen Kelly

A Lion purrs softly

A decade or so ago, November's annual Leonid meteor shower was all the rage among backyard observers. The shower produced rates that sometimes exceeded 1,000 meteors per hour. The Leonids have calmed down now, returning to more typical levels of about 20 meteors per hour.

Still, the Leonids will provide one of the best meteor shows in late 2011. Observers under clear, dark skies can expect to see 10 to 15 meteors per hour when the shower peaks November 17. A Last Quarter Moon will drown out the fainter streaks, but the brighter flashes still will look impressive.

Meteor showers arise when Earth collides with tiny bits of debris left behind by periodic comets. (The debris from a comet spreads out along its orbit, and these particles maintain similar orbits.) When the debris hits Earth's upper atmosphere, friction with the air causes the particles to burn up and leave behind streaks of light.

Astronomers name meteor showers after the constellation from which the meteors appear to radiate. Think of the geometry like this. Imagine driving a car through a snow shower. Although most of the snowflakes fall toward the ground, your forward motion makes them appear to be coming right at you. Look around and you'll notice that they appear to radiate from a point. It's an optical illusion caused by your perspective on viewing parallel "streaks."

Brilliant fireballs lit up the sky during the spectacular Leonid meteor shower of 2001. This year's shower peaks November 17, when astronomers expect up to 15 meteors per hour. Tony Hallas

Now switch your mind's eye to Earth speeding along its orbit around the Sun. The cometary debris replaces the snowflakes. As Earth runs into these particles, the resulting meteors appear to radiate from a point in the sky — the shower's radiant. In the case of the Leonids, the meteors appear to come from Leo the Lion.

Prospects for this year's other major showers range from great to terrible. The standout for 2011 comes in the year's first week. The Quadrantid shower peaks at New Moon and could deliver 100 meteors per hour under a dark sky. Conditions are nearly as good for May's Eta Aquarid shower because the waxing crescent Moon sets before the prime observing hours after midnight.

The second half of 2011 looks worse. August's Perseid shower peaks at Full Moon, while October's Orionids and November's Leonids both battle a Last Quarter Moon. And December's normally outstanding Geminid shower contends with a waning gibbous Moon.

Meteor showers in 2011

Name	Peak date	Moon's phase	Prospects
Quadrantids	Jan. 3	New Moon	Excellent
Lyrids	April 22	Waning gibbous	Poor
Eta Aquarids	May 6	Waxing crescent	Excellent
Perseids	Aug. 13	Full Moon	Poor
Orionids	Oct. 21	Last Quarter	Fair
Leonids	Nov. 17	Last Quarter	Fair
Geminids	Dec. 14	Waning gibbous	Poor

2011
November

S	M	T	W	T	F	S
		1	◐	3	4	5
6	7	8	9	●	11	12
13	14	15	16	17	◑	19
20	21	22	23	24	○	26
27	28	29	30			

4 The Moon passes 6° north of Neptune, 4 A.M. EDT

6 The Moon passes 6° north of Uranus, 9 P.M. EST

9 The Moon passes 5° north of Jupiter, 2 P.M. EST

Venus passes 4° north of Antares, 4 P.M. EST

Mars passes 1.4° north of Regulus, midnight EST

Mercury passes 1.9° north of Antares, midnight EST

14 Mercury is at greatest eastern elongation (23°), 4 A.M. EST

17 Leonid meteor shower peaks

19 The Moon passes 8° south of Mars, 5 A.M. EST

22 The Moon passes 7° south of Saturn, 5 P.M. EST

25 Partial solar eclipse, 1 A.M. EST

26 The Moon passes 1.7° north of Mercury, 5 A.M. EST

The Moon passes 3° north of Venus, 11 P.M. EST

2011
December

S	M	T	W	T	F	S
				1	◑	3
4	5	6	7	8	9	●
11	12	13	14	15	16	◐
18	19	20	21	22	23	○
25	26	27	28	29	30	31

1 The Moon passes 6° north of Neptune, 10 A.M. EST

4 The Moon passes 6° north of Uranus, 3 A.M. EST

Mercury is in inferior conjunction, 4 A.M. EST

6 The Moon passes 5° north of Jupiter, 3 P.M. EST

10 Total lunar eclipse, 10 A.M. EST

14 Geminid meteor shower peaks

17 The Moon passes 8° south of Mars, 8 A.M. EST

20 The Moon passes 7° south of Saturn, 5 A.M. EST

22 Solstice (northern winter/southern summer begins), 1 A.M. EST

Mercury passes 7° north of Antares, 3 P.M. EST

Mercury is at greatest western elongation (22°), 10 P.M. EST

The Moon passes 3° south of Mercury, 11 P.M. EST

27 The Moon passes 6° north of Venus, 6 A.M. EST

28 The Moon passes 6° north of Neptune, 8 P.M. EST

31 The Moon passes 6° north of Uranus, 11 A.M. EST

Taking a dip in Earth's shadow

An eclipsed Moon hangs above an observatory dome in Val Belair, Quebec, during the October 2004 total eclipse. This year, observers have the chance to view two total eclipses. Jay Ouellet

Few celestial events create bigger thrills than a total eclipse. Although solar eclipses deliver the most excitement, they occur in small geographic regions and often require a major investment in time and money to witness. Lunar eclipses are more subdued, but observers across half the world can see them. This year doesn't offer any total solar eclipses, but it does provide two exceptional total lunar eclipses.

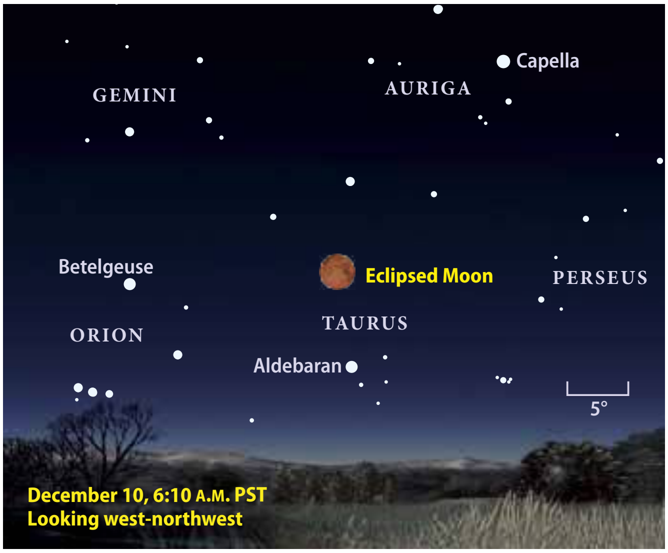
The best North American eclipse occurs December 10. For people in the western third of the continent, the Moon passes into Earth's shadow before dawn that morning. The partial phase of the eclipse begins at 4:46 A.M. PST. Totality commences at 6:06 A.M. PST and lasts for 51 minutes. Observers west of the Mississippi River can see at least some of the partial phases before the Moon sets.

Those along a line from Arizona to North Dakota will see the Moon set just as totality begins. Observers farther to the northwest will have even better views. Viewers in northern California, Oregon, and Washington State can see all of totality before moonset. And those in Alaska and Hawaii can experience the entire eclipse. Farther west, people throughout the Pacific Basin, Australia, and most of Asia also have ringside seats.

The Moon will pass through the southern half of Earth's shadow. This means the Moon's mountainous southern limb will remain brighter than the northern limb. In the sky, the eclipsed Moon nestles between the horns of Taurus the Bull.

The Moon dips even deeper into Earth's shadow June 15. Observers across Africa and southern Asia will have the best views, although those in Australia, eastern South America, and much of Europe will see at least part of the festivities. (For those in the United Kingdom, the totally eclipsed Moon rises during twilight.)

The partial phase gets underway at 18h23m UT and totality begins 60 minutes later (at 19h23m UT). Totality lasts an impressive 1 hour and 40 minutes, concluding at 21h03m UT, and the concluding partial phases last 60 minutes longer.



Earth's shadow covers the Moon December 10, creating a total lunar eclipse for lucky viewers on Earth's night side. The Moon then lies between the horns of Taurus the Bull. *Astronomy*: Roen Kelly

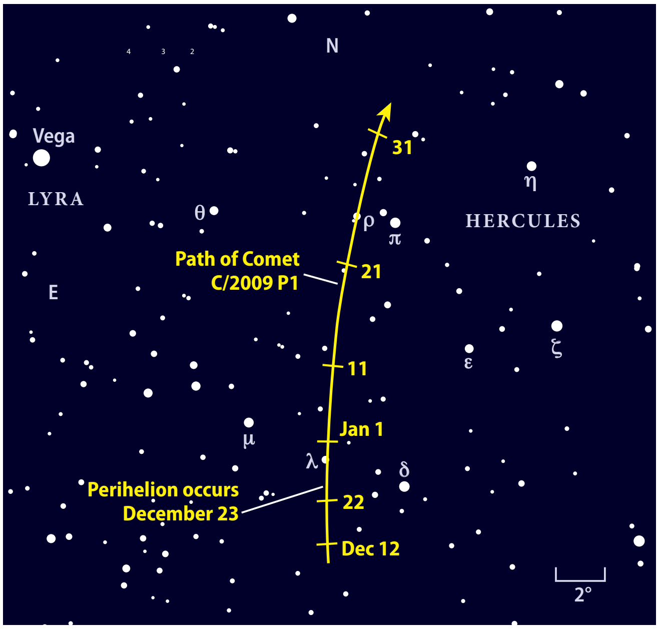
A winter comet treat

Although Northern Hemisphere observers haven't had a truly bright comet visible in a dark sky since Comet C/1995 O1 (Hale-Bopp) in 1997, several have grown bright enough to be nice binocular objects. It looks like another one is coming down the pike. If preliminary estimates are right, Comet C/2009 P1 (Garradd) should be easy to see through binoculars in late 2011 and early 2012.

Australian astronomer Gordon Garradd discovered this comet in August 2009. It reaches perihelion, its closest point to the Sun, December 23, but it should be a better target in January. It then lies closer to Earth, so it appears a bit brighter, and it stands higher in the night sky.

If the comet peaks at its expected 6th magnitude, it will be well within reach of 7x50 binoculars. It even might be visible to naked eyes from dark locations on moonless nights, particularly if Garradd has an outburst and brightens more than astronomers predict.

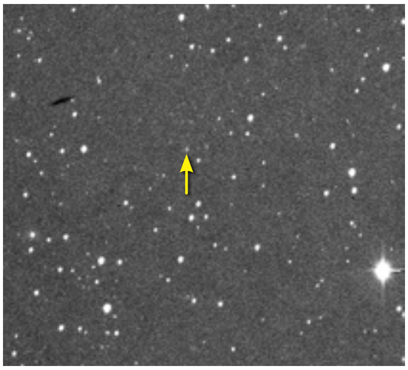
Comet Garradd moves slowly during much of 2011. On August 2, the comet passes within a Moon's breadth of the globular cluster M15 in Pegasus. Although Garradd likely will be 8th magnitude or fainter, the pair should make a fine photo target. In mid-August, it passes through the delightful star pattern of Delphinus. The comet reaches Sagitta in late August. On the 26th, it lies in the same telescopic field of view as another globular cluster, M71.



Follow Comet C/2009 P1 (Garradd) as it heads west and then north through Hercules. The comet could reach 6th magnitude at its peak in early 2012. *Astronomy*: Roen Kelly

Comet Garradd crosses into Hercules September 11, when it lies some 20° south of summer's brightest star, Vega. But the comet's motion soon slows to a crawl. It spends the next 2 months creeping westward before veering north. It doesn't pick up much speed until it gets closer to Earth in January, when it lies more than halfway to the zenith in the predawn sky.

Comet Garradd is apparently on its first visit to the inner solar system. The brightnesses of such comets are notoriously difficult to predict. Sometimes they appear surprisingly bright on their approach but then fizzle out. If that happens to Garradd, many backyard observers will forget about it before 2012. But occasionally such comets put on great shows. No one knows what this comet will do, so it's best to keep watching.



The comet glowed at magnitude 17.5 when Gordon Garradd discovered it in August 2009. Gordon Garradd

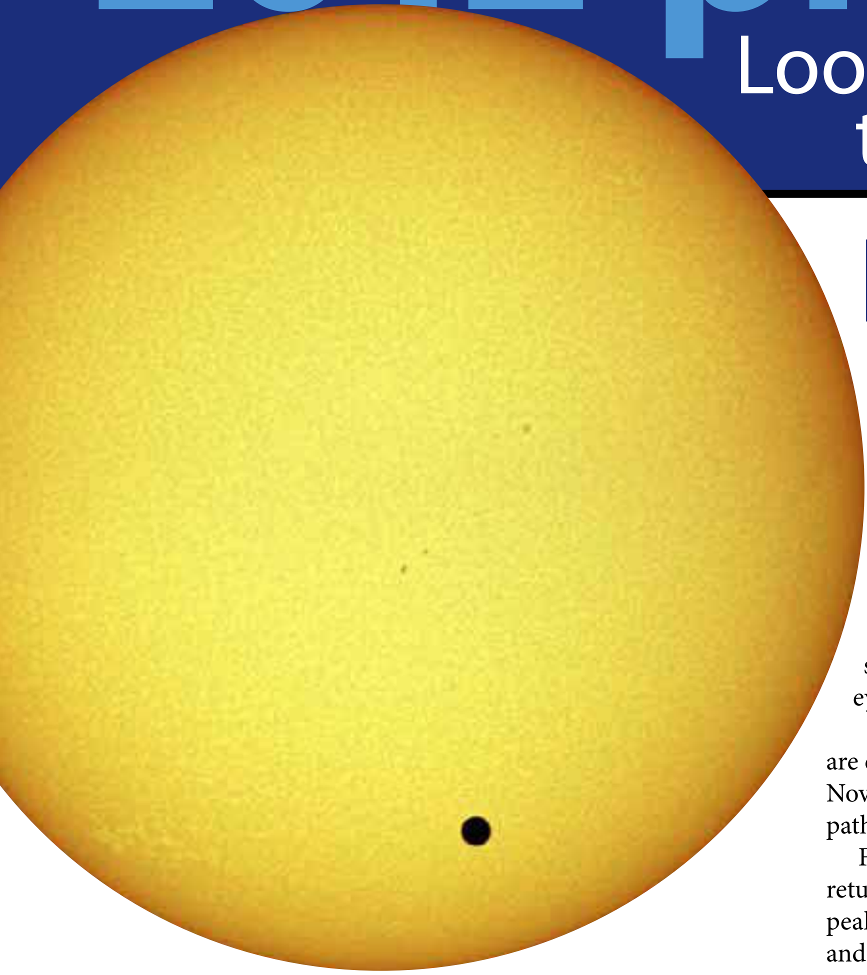
2012
January

S	M	T	W	T	F	S
◑	2	3	4	5	6	7
8	●	10	11	12	13	14
15	◐	17	18	19	20	21
22	○	24	25	26	27	28
29	◑	31				

2	The Moon passes 5° north of Jupiter, 10 P.M. EST	👁 🔭
4	Quadrantid meteor shower peaks	👁
13	Venus passes 1.2° south of Neptune, 2 A.M. EST	🔭
14	The Moon passes 9° south of Mars, 2 A.M. EST	👁 🔭
16	The Moon passes 6° south of Saturn, 2 P.M. EST	👁 🔭
25	The Moon passes 6° north of Neptune, 7 A.M. EST	🔭
26	The Moon passes 7° north of Venus, 2 P.M. EST	👁 🔭
27	The Moon passes 6° north of Uranus, 9 P.M. EST	🔭
30	The Moon passes 5° north of Jupiter, 10 A.M. EST	👁 🔭

2012 preview

Looking ahead to next year...



Venus transits the Sun June 5/6, 2012, for the first time since June 2004 (shown here) and the last time until December 2117. Paolo Lazzarotti

If unusual astronomical events excite you, then 2012 may blow you away. The rarest of all predictable events — a transit of Venus — takes place June 5 or 6 (the date depends on where you live). Venus' black disk last crossed the Sun's disk in 2004 and won't do so again until 2117. So, if not exactly a once-in-a-lifetime experience, a Venus transit certainly qualifies as a twice-in-a-lifetime event.

Viewers in northern North America, northern Europe, northern and eastern Asia, Hawaii, New Zealand, and eastern Australia will see the transit's entire 6-hour duration. Those in the rest of North America will witness the early stages before sunset; those in the rest of Asia, most of Europe, and eastern Africa will see the final stages after sunrise. You can view the transit with naked eyes or with optical aid as long as you use a safe solar filter.

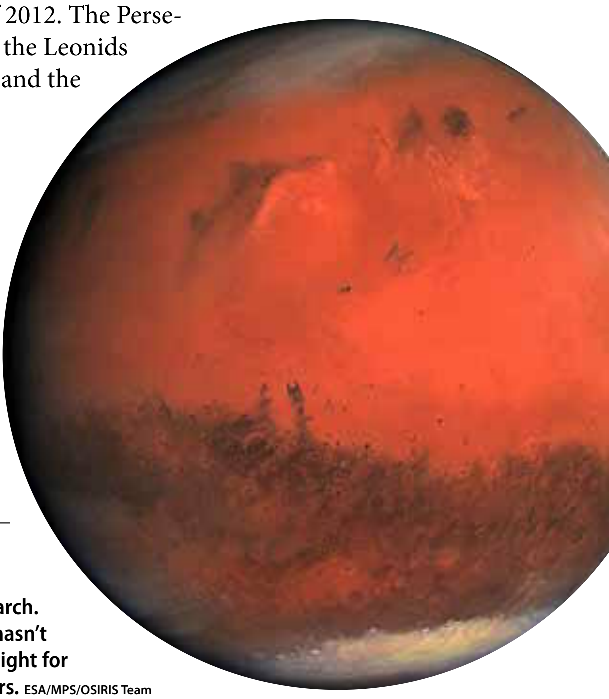
Although not as rare as a Venus transit, total solar eclipses are even more spectacular. The next total eclipse takes place November 13/14. Viewers can watch totality from a narrow path that cuts across northern Australia and the Pacific Ocean.

For planet-watchers, the highlight of 2012 may be the return of Mars to prominence. It will reach opposition and peak visibility in March for the first time in 26 months. Saturn and Jupiter also put on nice displays, with Saturn at its best in April and Jupiter in December.

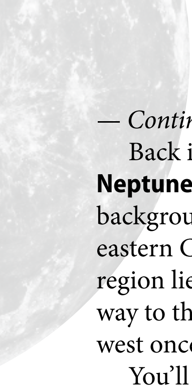
Meteor observers should target the major showers in the second half of 2012. The Perseids in August, the Leonids in November, and the Geminids in December all peak with the Moon either out of the sky or appearing as a thin crescent that won't adversely affect the viewing.

Bill Lider

A diamond ring flashes at third contact during the July 11, 2010, solar eclipse. Totality returns to Earth's Southern Hemisphere November 13/14.



Mars returns to prominence in February and March. The Red Planet hasn't appeared this bright for more than 2 years. ESA/MPS/OSIRIS Team



— Continued from page 36

Back in the evening sky, **Neptune** lurks among the background stars of northeastern Capricornus. This region lies about a third of the way to the zenith in the southwest once darkness falls.

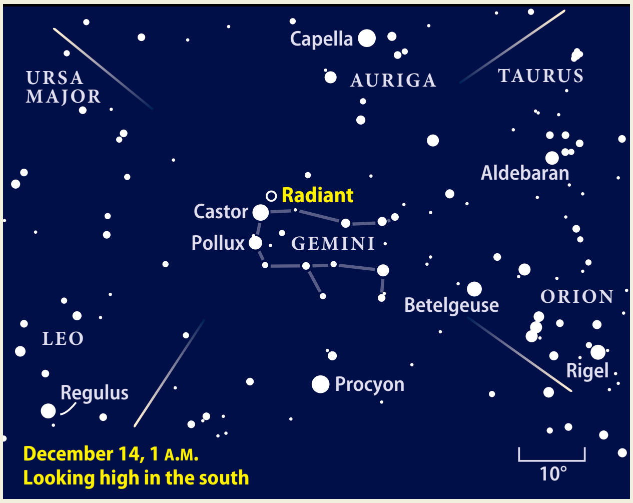
You'll need binoculars or a telescope to find Neptune. First, locate 3rd-magnitude Delta (δ) Capricorni, the brightest star in the constellation. Then shift your gaze 3° northeast to 5th-magnitude Mu (μ) Cap. Neptune lies 0.2° north of this star December 1. The planet moves eastward during December, and its worsening alignment with Mu will make it harder to zero in on. Neptune glows at magnitude 7.9, which makes it easy to spot through binoculars. A telescope reveals its 2.2"-diameter disk and subtle blue-gray color.

Jupiter dominates the southern sky as darkness falls. Not only is it brilliant, shining at magnitude –2.5, but it also lies among the faint stars on the border between Aquarius and Pisces. It comes into view less than a half-hour after sunset and doesn't set until around midnight. On the evening of December 13, the First Quarter Moon lies within the "Circlet" asterism of Pisces 7° north of Jupiter.

Three days later, Jupiter reaches quadrature, when a line drawn from the Sun to Earth and then to Jupiter forms a 90° angle. Sharp-eyed observers viewing the planet's 41"-diameter disk through a telescope will notice its eastern limb appears softer than the western one. That's because the geometry gives us a peek onto the planet's nightside on its eastern limb. Jupiter's shadow also stretches far east of the planet from our perspective at quadrature. Whenever a moon is in eclipse and hidden by this extended shadow, it reappears well after clearing the limb, as if decloaking from deep space.

Martin Ratcliffe *provides professional planetarium development for Sky-Skan, Inc., in Nashua, New Hampshire. Meteorologist* **Alister Ling** *works for Environment Canada in Edmonton, Alberta.*

Meteor watch



Geminid meteors will light up the sky after midnight December 13/14 once the First Quarter Moon sets. *Astronomy*: Roen Kelly

Dark skies as the Twins' shower peaks

Observers should be in for a treat the night of December 13/14, when the annual Geminid shower reaches its peak. This shower ranks among the best and most reliable, typically producing 100 to 120 meteors per hour for viewers under dark skies. And this year, the First Quarter Moon sets around midnight, creating ideal conditions for those watching in the predawn hours.

The shower's radiant lies just north of Castor, the bright star in the northern part of Gemini the Twins. This region passes nearly overhead from mid-northern latitudes around 2 A.M. local time. The high altitude only enhances the number of often-bright Geminids streaking across the sky. Rates for this shower remain decent a day on either side of the peak, so target the morning of December 13 or 15 if the weather looks bad on the 14th.

Rising **Moon**

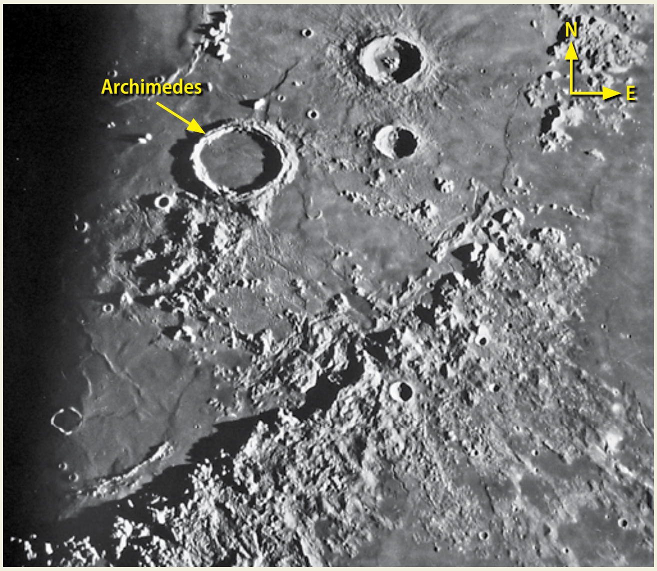
Flooded by a flow of lava

If you're outside the evening of December 13, perhaps in anticipation of watching the Geminid meteor shower after midnight, behold the glory of the First Quarter Moon. Through a telescope, your eyes will first notice the breathtaking chain of craters just south of the lunar equator. Ptolemaeus, Alphonsus, and Arzachel stretch from north to south along the terminator — the line that separates day from night and cuts the Moon in half at First Quarter phase.

But our main target this month lies halfway from the equator to the north pole. The crater Archimedes is a picture of perfection: a sharp circular rim that casts shadows onto a smooth dark floor.

Most big craters have central peaks, but Archimedes, which spans some 50 miles, doesn't. Where did it go? A massive impact carved this crater and presumably forged a central peak. But an intense period of lunar volcanism followed much later. Lava rose through the fractured floor and completely buried the mountain.

Take a closer look at Archimedes' interior. The jagged shadows at sunrise exaggerate its topography, but they still show us that Archimedes is old. Eons of impacts have battered the rim into an undulating ridge, creating modestly irregular shadows. Notice how the younger craters nearby have sharper rims that cast saw-tooth shadows.



A huge impact created the picture-perfect crater Archimedes, which stands out nicely near First Quarter Moon. *Consolidated Lunar Atlas*/UA/LPL

When to view **the planets**

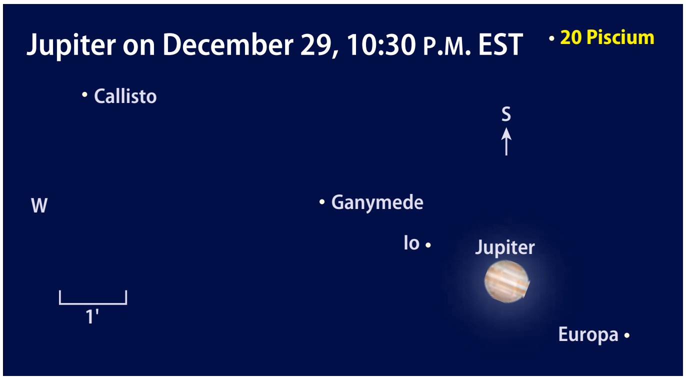
EVENING SKY	MIDNIGHT	MORNING SKY
Mercury (southwest)		Mercury (southeast)
Mars (southwest)		Venus (southeast)
Jupiter (south)		Saturn (southeast)
Uranus (south)		
Neptune (southwest)		

Jupiter threw veteran observers for a loop last April. As it returned to view in the morning sky after passing behind the Sun, its normally dark South Equatorial Belt (SEB) had faded nearly to invisibility and the Great Red Spot appeared more colorful than it had in years. These changes persisted throughout the summer months.

Now, with 2010 coming to a close, has the SEB returned? As this issue went to press in September, the belt remained highly subdued. But Jupiter has shown a penchant for quick and dramatic recoveries on the handful of previous occasions when the SEB went missing. Only those who observe the giant planet will see the belt return, so be sure to make it a regular stop in your observing routine.

Jupiter's four bright moons always put on a nice display as they circle the planet. These so-called Galilean moons — Io, Europa, Ganymede, and Callisto — all glow around 5th magnitude. In fact, if not for Jupiter's glaring presence, the four would be visible to naked eyes under a dark sky.

During the last few days of December, Jupiter appears to gain an additional moon. On the 29th, the planet passes just north of the 5.5-magnitude star 20 Piscium, which will appear in any field of view that includes the moons. You can tell the star apart because all the moons orbit in Jupiter's equatorial plane while the star lies well off this line.



Jupiter gains a "moon" in late December, when the giant planet passes near the 5.5-magnitude star 20 Piscium. *Astronomy*: Roen Kelly

Jupiter serves as a guide to **Uranus**. The two planets lie within 3° of each other all month, well within the same binocular field. And by New Year's Eve, Jupiter's faster eastward motion has carried it to a spot less than a degree south of Uranus. You'll see both in the field of a low-power eyepiece through almost any telescope.

Uranus glows at magnitude 5.8, roughly 2,000 times fainter than Jupiter. Still, you can spy the distant planet without optical aid from a dark site. Binoculars show it easily, and a telescope reveals its distinctive blue-green color and 3.5"-diameter disk.

About 2 hours after Jupiter sets in the west, you can find **Saturn** rising in the east. The ringed planet appears nearly halfway to the zenith in the southeastern sky by the time twilight commences. It lies among the background stars of Virgo, almost directly above that constellation's brightest star, Spica. At magnitude 0.8, golden-colored Saturn appears almost imper-

Comet search

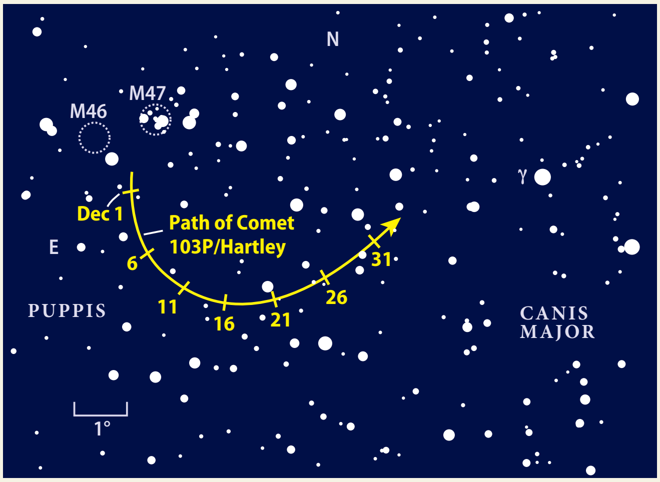
Handsome Hartley hangs low in the south

If it lives up to expectations, Comet 103P/Hartley should be the comet of the year. Although it reached its peak in November, this comet remains a delight in December. Astronomers predict it to glow around 6th magnitude this month. Although that's a bit too faint to pick up with naked eyes, even from a dark site, its appearance through binoculars or a telescope should be wonderful. The rich star fields of Puppis and Canis Major add to the scene by coating the background sky with diamond dust.

The best views should come early in the month when Hartley shines brighter and the Moon is out of the way. The comet's head, or coma, appears as a fuzzy circular glow. It looks distinctly different from the star clusters M46 and M47, which sparkle just a few degrees away.

The comet's orbit brought it closest to the Sun in late October, so it now should sport two nice tails. The main one spreads out in a modest fan shape. It appears generally white from sunlight scattering off myriad dust particles. The Sun plays a key role here: Not only does it supply the energy to liberate gas and dust from the comet's nucleus, but its radiation also pushes the dust particles deeper into the solar system. Because the dust tail's trailing edge spreads out, the southern flank should be diffuse and blend gradually into the sky.

In contrast, the dust tail's leading edge (on the comet's northern side) should appear sharper. Look for a straight pale-blue glow just off this edge of the dust tail. This is a tail of ionized gas carried away from the Sun by the solar wind. Color is notoriously difficult to see at the eyepiece, however. You'll likely need a 10-inch or larger scope to stimulate your eye's color receptors.



Comet 103P/Hartley could reach 6th magnitude as it passes through the rich star fields of Puppis and Canis Major. *Astronomy*: Roen Kelly

Locating **asteroids**

Iris skirts the Crab's "other" star cluster

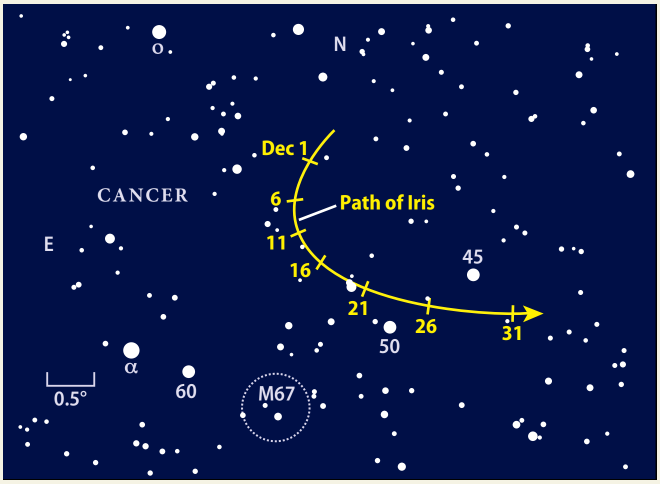
It's easier to find an asteroid when it lies near a familiar object. This month, the bright star cluster M67 in Cancer the Crab makes a conspicuous backdrop for 7 Iris. You can find the pair climbing the eastern sky in late evening and high in the south before dawn.

Cancer's sparkling Beehive Cluster (M44) usually upstages M67. But through a telescope, M44's stars spread out so much that you can nearly see through it. M67 looks much more like a cluster.

At magnitude 8.6 in mid-December, Iris shows up nicely through a 4-inch scope from the suburbs. This region lies far enough from the Milky Way that the background stars tend to be relatively faint and spread out, making Iris easier to find. Just scoot 1° or 2° northwest of M67 and use the chart at right to focus on the correct location.

On December 13, Iris forms a tight pair with a star of similar brightness. And on the 20th, you can see the asteroid pulling away from an unequal pair of brighter stars. With good markers like these, a couple of hours is all it takes to notice Iris' changing position.

Englishman John Russell Hind discovered Iris in August 1847. It was the seventh asteroid discovered, and the first of 10 for Hind.



Iris brightens from magnitude 8.9 to 8.3 as it treks across Cancer the Crab. The asteroid's proximity to the splendid star cluster M67 will make it easier to find. *Astronomy*: Roen Kelly

ceptibly brighter than blue-white Spica.

Saturn offers spectacular views to anyone observing it through a telescope. The rings tilt 9° to our line of sight in early December and 10° by year's end. Over the same period, the ring-span increases from 37" to 39". You won't have any problem seeing the Cassini Division, the dark gap that separates the outermost A ring from the brighter B ring.

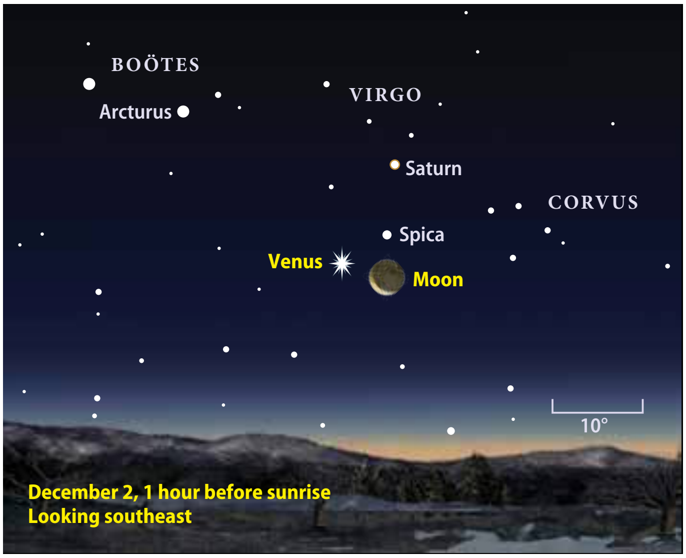
Venus is a spectacular sight before dawn. It rises before 4 A.M. local time all month — more than 3 hours before the Sun — and appears high in the southeast before twilight starts to paint the sky. It reaches peak brilliance in early December, when it shines at magnitude –4.9 and appears 25 times brighter than the night sky's brightest star, Sirius.

As pretty as Venus looks when standing by itself, it reaches another level when the Moon passes by. Observers have two chances to see such a conjunction this month. On December 2, the two objects rise nearly side by side, with the Moon's 13-percent-illuminated crescent on the right. The scene nearly repeats itself on the 31st, but this time the Moon appears 16 percent lit and rises some 15 minutes after Venus.

A telescope reveals dramatic changes on Venus during December. When the month begins, the planet's disk appears 42" across and just one-quarter lit. By the 31st, its diameter has shrunk to 27" while its phase has waxed to 45 percent lit.

Although the planets offer high drama in December, the month's main event involves the Moon. On the night of December 20/21, the Moon passes through Earth's shadow and creates a **total lunar eclipse** for viewers across North America and the Pacific. The event takes place just 15 hours before the winter solstice, which places the Moon exceptionally high in the winter sky, near the Taurus-Gemini border.

The Full Moon enters Earth's dark umbral shadow at 1:33 A.M. EST December 21 (10:33 P.M. PST on the 20th). As the Moon dips deeper into our planet's shadow during the next hour or so, darkness gradually overtakes the brilliant orb.



Venus receives a visit from a waning crescent Moon December 2, just 2 days before the planet reaches greatest brilliancy. *Astronomy*: Roen Kelly

The eclipse's total phase begins at 2:41 A.M. EST. The Moon likely will take on an orange-red hue during totality — the exact color and brightness depend largely on how dusty and cloudy Earth's atmosphere is. The sky certainly will grow darker, allowing the bright winter stars surrounding the Moon to spring back to prominence.

Totality ends 72 wonderful minutes after it begins, at 3:53 A.M. EST, and the concluding partial phases take another 68 minutes to play out. Weather is the only thing that can disrupt your view. If you miss this one, observers in western North America will have another chance in December 2011. (Those in Africa, Asia, and Europe get an earlier view, in June 2011.) After that, it's a long wait until April 2014. ◑

How five DOOME missions triumphed in the end

Like the mythic Phoenix, these spacecraft rose from the ashes of near-certain failure.

by Richard Talcott

No one ever said spaceflight would be easy. Humans were never designed to survive the frigid, airless, and radiation-filled environment that exists outside Earth's atmosphere. But even unmanned spacecraft face constant threats in the great beyond.

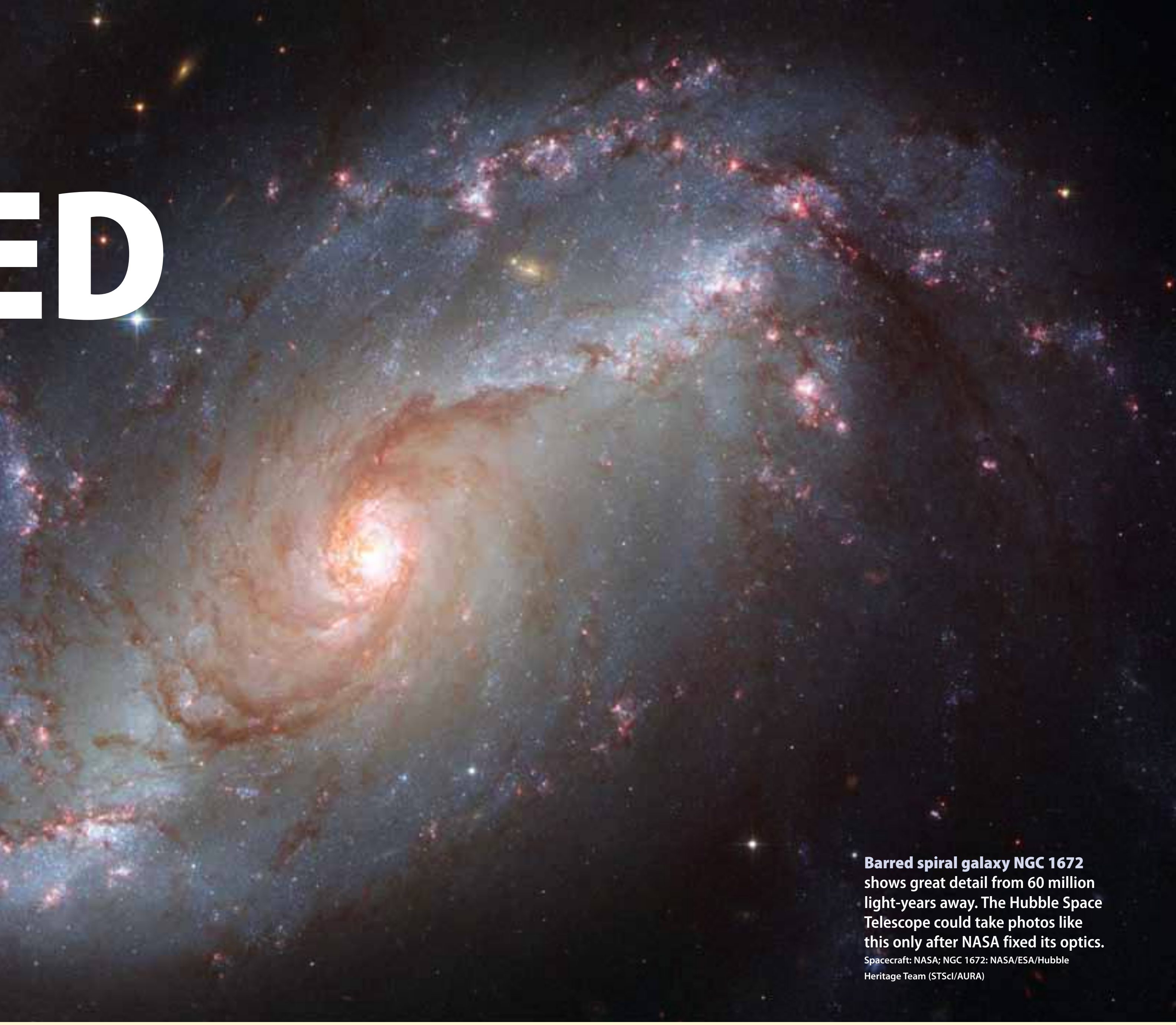
Some robotic missions beat the odds and became spectacular successes. For example, the twin Mars rovers, Spirit and Opportunity, survived for more than 6 years on the martian surface — even though they were designed to last just 3 months. And the Solar and Heliospheric Observatory continues to monitor the Sun 15 years after its launch. Dozens of other spacecraft completed their missions with few, if any, hiccups, and many continue to do so.

Unfortunately, the list of spacecraft failures runs nearly as long. Mars has been the graveyard for several mishaps. In the past 20 years alone, Mars Observer, Mars Climate Orbiter, Mars Polar Lander, and Beagle 2 all succumbed to the "Mars curse." In fact, failure at Mars is about as common as success.

Other missions, such as the Comet Nucleus Tour that was to explore comets 2P/Encke and 73P/Schwassmann-Wachmann up close, never even made it out of Earth orbit.

A few spacecraft suffered initial blows that rendered them nearly useless, but through a combination of ingenuity, perseverance, and, in a few cases, serendipity, people on the ground managed to overcome the problems and fully restore the missions. Here, *Astronomy* looks at five missions — Skylab, Voyager 2, Hipparcos, the Hubble Space Telescope, and NEAR Shoemaker — that turned disaster to fortune and expanded our knowledge of the universe.

Richard Talcott *is an* Astronomy *senior editor and author of* Teach Yourself Visually Astronomy *(Wiley Publishing, 2008).*



Barred spiral galaxy NGC 1672 shows great detail from 60 million light-years away. The Hubble Space Telescope could take photos like this only after NASA fixed its optics. Spacecraft: NASA; NGC 1672: NASA/ESA/Hubble Heritage Team (STScI/AURA)

Skylab lifts off May 14, 1973. The Saturn V launch encountered problems 63 seconds later. NASA

Skylab space station

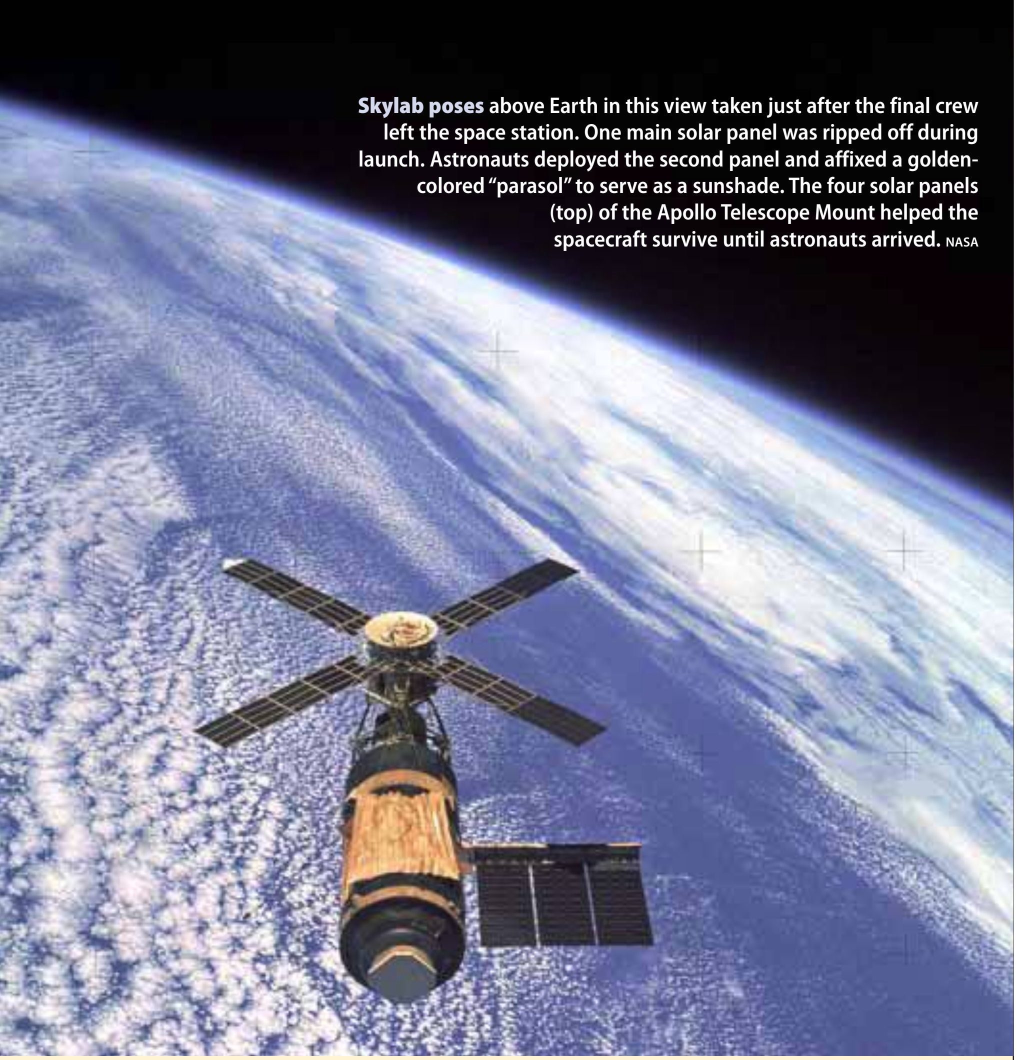
Salvaging a crippled spacecraft

The final launch of a Saturn V rocket occurred May 14, 1973. And it went without a hitch — for 63 seconds. The massive rocket's cargo was the Skylab space station, a laboratory that NASA planned to use to test human endurance in the weightlessness of space. But Skylab also housed the Apollo Telescope Mount (ATM), which would observe the Sun and other celestial objects in unprecedented detail.

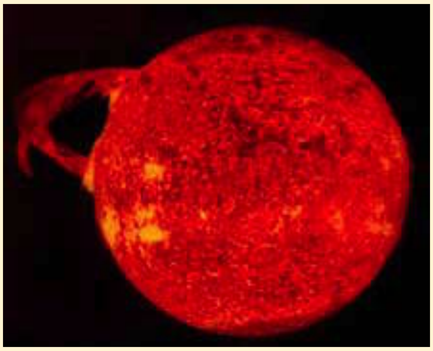
Skylab's problems began when the craft's meteoroid shield accidentally deployed 63 seconds after liftoff. Atmospheric drag ripped the shield off the station, triggering a nearly lethal cascade of events. The shield disturbed the mounting for one of the two main solar arrays, causing it to partially deploy. Exhaust from the rocket's engines then blew off this array.

Meanwhile, debris from the shield jammed the second solar array against Skylab's side, where it could generate hardly any power. To compound the problem, the meteoroid shield also was supposed to serve as a sunshade for the crew's work and living areas, so the spacecraft's interior overheated.

Fortunately, NASA originally conceived the ATM as an independent vehicle, so it was essentially strapped onto the main craft and had a separate system of solar arrays. The ATM's solar panels kept Skylab alive until the



Skylab poses above Earth in this view taken just after the final crew left the space station. One main solar panel was ripped off during launch. Astronauts deployed the second panel and affixed a golden-colored "parasol" to serve as a sunshade. The four solar panels (top) of the Apollo Telescope Mount helped the spacecraft survive until astronauts arrived. NASA



Naval Research Laboratory

A mammoth prominence erupts from the Sun's surface in this view from Skylab taken at extreme ultraviolet wavelengths in 1973.

first astronauts arrived May 25. The three-person crew freed the station's remaining panel and erected a makeshift sunshield.

Orbiting Earth at an altitude of 270 miles (435 kilometers), Skylab enjoyed a view of the Sun unmarred by our planet's atmosphere. From this vantage point, the ATM could view our star at X-ray and ultraviolet wavelengths, radiation that can't penetrate Earth's protective air blanket.

Skylab gave solar scientists their first clear looks at how disturbances on the Sun's surface, or photosphere, affect magnetic fields, which in turn alter the structure of the Sun's outer corona. It also revealed the magnetic nature of active regions and established the relationship between coronal holes, the large dark areas visible in X-ray photos, and the solar wind that blows through the solar system.

The ATM didn't spend all its time observing the Sun, however. The astronauts took time to view Comet C/1973 E1 (Kohoutek) — the infamous "Comet of the Century" that fizzled out — as it passed close to the Sun in late 1973.

Although the third and final crew left Skylab February 8, 1974, the space station wasn't done making news. On July 11, 1979, the spacecraft succumbed to atmospheric drag exacerbated, ironically, by greater-than-predicted solar activity. Skylab came back to Earth in pieces over Western Australia and the Indian Ocean, but not before blazing the way for future solar missions.

Voyager 2

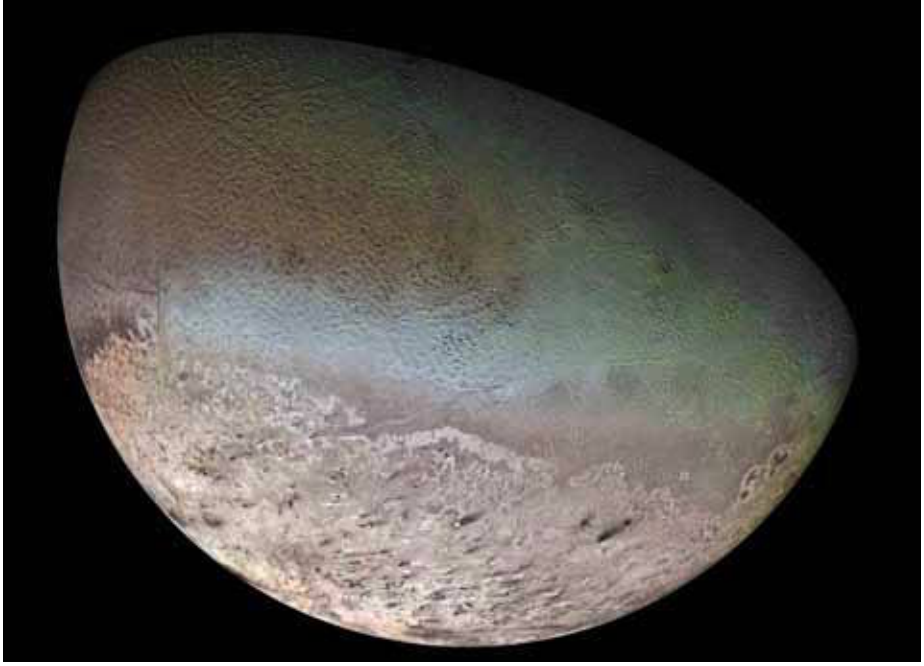
A voyage of discovery

The problems that befell Skylab were obvious to anyone who looked at the damaged spacecraft's exterior. The troubles that Voyager 2 experienced were internal and out of sight, but they threatened to derail the spacecraft just as severely.

Although Voyager 2 ended up as arguably the most successful planetary mission ever, it seemed snakebit from the start. About 3 weeks before its August 20, 1977, launch, two of the spacecraft's three main computer subsystems failed. NASA therefore substituted a spare spacecraft that became Voyager 2. (Voyager 1 launched September 5, but earned top billing by taking a shorter, faster trajectory.)

Within an hour of launch, Voyager 2 experienced several more problems. One stabilizing gyroscope started to act flaky, but it returned to normal operations without help from the ground. Then, an apparent problem in one computer subsystem caused the spacecraft to switch to a backup, resulting in the loss of some flight data. Finally, the boom that held the science instruments apparently failed to extend completely and lock into place. Ground controllers eventually decided that the problem lay not with the boom but with the sensor that was supposed to signal that it had locked.

Voyager 2 blasts off from Cape Canaveral atop a Titan/Centaur rocket August 20, 1977. Computer and other problems threatened the mission starting less than an hour after launch. NASA



Triton's melon-textured surface and erupting geysers (the dark streaks) posed for Voyager 2 August 25, 1989. NASA/JPL/USGS

Voyager 2 continued to act erratically during its first year in space. Thrusters fired without cause, filter wheels became stuck, and computer systems overrode commands from the ground. The hardware seemed to be fine, but the onboard computers were acting a little like Hal in *2001: A Space Odyssey*. NASA eventually realized that engineers had programmed the computers to be overly sensitive — any minor fluctuation in the spacecraft's environment caused a huge overreaction. Once NASA reprogrammed the computers, the problems mostly disappeared.

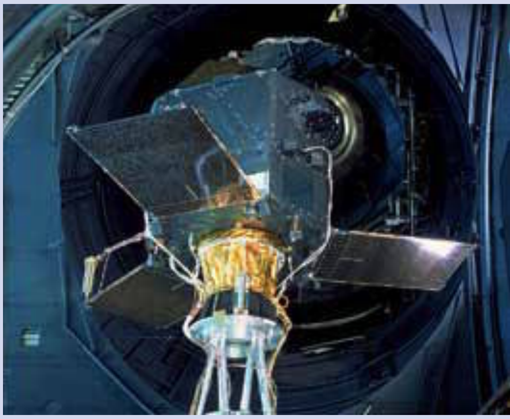
But the troubled probe faced one more crisis, its most serious yet. In April 1978, a power surge in the craft's primary radio receiver blew its fuses. The receiver was dead. To make matters worse, the demise occurred less than a day after engineers learned that its backup was not working properly. For 7 days, ground controllers couldn't communicate with Voyager 2. When the backup came online again, NASA sent a huge volume of instructions to the craft so it could execute reduced missions at both Jupiter and Saturn if the backup failed completely. But it didn't — and it's still operating effectively, if a little quirkily, more than 30 years later.

Voyager 2 examined Jupiter, Saturn, and these planets' large moons in exquisite detail. Voyager 1 made the main discoveries at these worlds because it flew past them before its sister craft. But Voyager 2 often passed closer to a given moon or flew above a different hemisphere, revealing details hidden to Voyager 1.

Neptune's atmosphere featured giant storms and intricate cloud patterns when Voyager 2 flew by in 1989. NASA/JPL

And Voyager 2 made the first, and as yet only, flybys of the ice giants Uranus (in 1986) and Neptune (in 1989). It discovered large magnetic fields around both planets and revealed details in their intricate ring systems. Perhaps most surprisingly, the spacecraft found colossal storms on Neptune, a world astronomers thought would be too cold for such activity. And Neptune's large moon Triton shocked scientists with its strange surface and geyser-like eruptions.

Voyager 2 has now logged more than 13 billion miles (21 billion km) and is exploring the region where the solar wind interacts with interstellar space. No one knows how much longer Voyager 2 and its twin will last, but NASA scientists plan to keep listening to their weakening signals as long as possible.



The Hipparcos spacecraft, seen here while being tested on Earth, precisely measured star positions despite never reaching its intended orbit. ESA

Hipparcos satellite

To measure the stars

If there's a theme to our first three missions, it's that the initial hours after launch are often the most critical. In the case of the European Space Agency's Hipparcos satellite, designed to precisely measure star positions and distances, that period almost meant the end of the mission.

On August 8, 1989, Hipparcos roared off its launch pad in French Guiana and reached its intended transfer orbit. But the spacecraft's apogee boost motor failed to ignite, stranding Hipparcos in its highly elliptical transfer orbit. It was supposed to enter a 24-hour geostationary orbit, where it would circle Earth at an altitude of about 22,000 miles (36,000 km) and remain in constant contact with the ground station in Germany.

The actual orbit kept the maximum distance at 22,000 miles, but the minimum distance was only about 310 miles (500 km), and Hipparcos orbited Earth every 10.7 hours. On this path, the spacecraft passed through Earth's Van Allen radiation belts, where energetic particles pelted the solar panels and degraded their performance. Hipparcos also experienced eclipses by Earth occasionally lasting longer than 60 minutes, forcing the probe into hibernation mode. And the spacecraft remained out of contact with Germany nearly 70 percent of the time.

To top it off, Hipparcos carried an extra 1,015 pounds (460 kilograms) of fuel — the unburned propellant — which made controlling the satellite more difficult.

For months, scientists didn't know if they could salvage the mission. Many thought it would be a bust, and few thought it would survive long enough to meet its objectives. But the European Space Agency nursed Hipparcos through a 3.5-year mission — a year longer than originally planned — that ended up exceeding pre-launch goals.

Above the distorting effects of Earth's atmosphere, Hipparcos gauged star positions with unparalleled accuracy. Then, by comparing a star's position from multiple points in Earth's orbit, astronomers used geometry to calculate the star's distance.

The spacecraft's main instrument precisely measured positions of 118,218 stars. An auxiliary star mapper pinpointed far more stars with lesser but still unmatched accuracy. This catalog totals 2,539,913 stars and includes 99 percent of all stars brighter than 11th magnitude.

But Hipparcos did far more than fix the distances to a few million stars that lie close to Earth. Astronomers use these nearby stars to calibrate the distances to farther objects, eventually stretching to the edge of the cosmos. So, Hipparcos helped establish accurate distances throughout the universe.

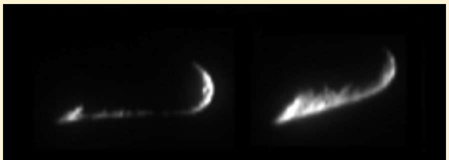
Hubble's primary mirror gets polished at Perkin-Elmer's large optics fabrication facility. Unfortunately, optical engineers already had ground the mirror to the wrong shape. NASA/MSFC

Hubble Space Telescope

Trouble for Hubble

The tribulations of the Hubble Space Telescope started long before astronauts on the space shuttle *Discovery* deployed the orbiting observatory April 25, 1990. But no one suspected a problem until Hubble returned its first photographs and scientists saw fuzzy halos surrounding stars — the telescope's primary mirror was producing out-of-focus images.

Optical engineers had polished the mirror to near perfection. If you could scale the mirror to the size of Earth, the biggest bump or dip would be just 6 inches (15 centimeters). Yet the engineers ground the mirror to the wrong shape: Its



NEAR Shoemaker flew past Eros December 23, 1998, after the spacecraft's main engine failed to fire correctly. These were the best images the probe managed during the flyby. NASA/JHUAPL

NEAR Shoemaker

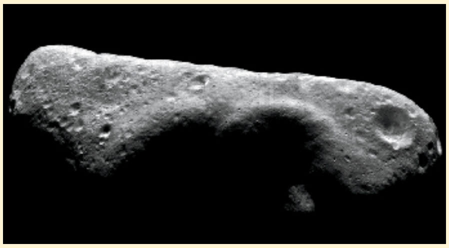
A NEARly missed opportunity

Unlike the previous four missions, the Near Earth Asteroid Rendezvous (NEAR) Shoemaker spacecraft enjoyed fine health at the start. It launched from Cape Canaveral February 17, 1996, and then took a long, looping path to its target: near-Earth asteroid Eros. Along the way, it waltzed past the asteroid Mathilde in June 1997 and swung by Earth in January 1998. These flybys went off without a hitch.

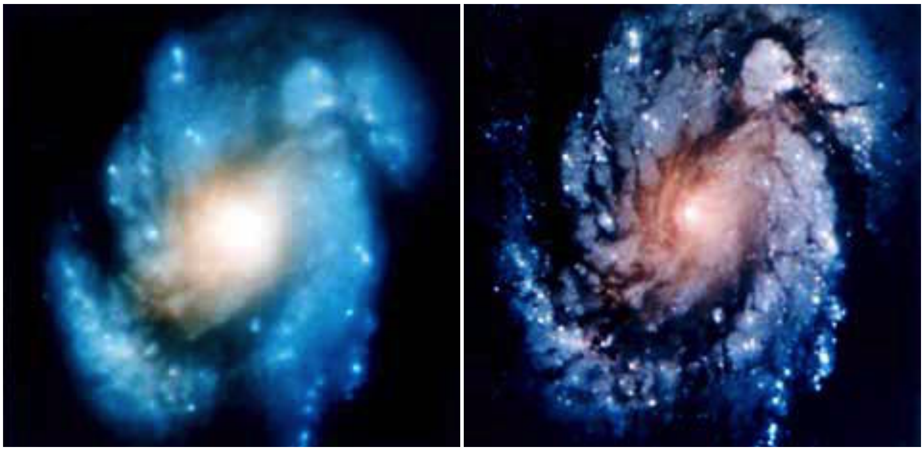
As NEAR Shoemaker approached Eros in December 1998, the plan called for the spacecraft to fire its main engine four times, each about a week apart, to slow the spacecraft to match Eros' speed and ultimately orbit the asteroid. The first and biggest engine burn was set for December 20. But something went terribly wrong. Instead of a 15-minute burn, the engine shut off less than 2 seconds after it started.

NEAR Shoemaker veered off course and lost contact with Earth. There were no communications for 27 hours. When the spacecraft did phone home, mission planners learned the probe was about 1,860 miles (3,000 km) off course. Even worse, the spacecraft had tumbled out of control. Small thrusters fired some 600,000 times trying to right the craft, draining much of the reserve fuel. And the solar panels spent too much time pointing away from the Sun, so the battery nearly discharged.

It was then too late to save the planned orbital mission — NEAR Shoemaker



NEAR Shoemaker eventually landed just within the shadow slightly left of center in this view of Eros' southern hemisphere. NASA/JHUAPL



The core of spiral galaxy M100 looks blurry in an image (left) taken through Hubble's first-generation camera, but comes into sharp focus through the Wide Field and Planetary Camera 2 after astronauts serviced Hubble in 1993. NASA

edges were 2 micrometers too flat (about 1⁄50 the width of a human hair). On an Earth-sized Hubble mirror, the edge would be 35 feet (11 meters) too low.

Of the blurry images that resulted, one scientist quipped that he could get equivalent results with an 8-inch amateur scope, albeit if it were placed on Mauna Kea. Astronomers estimated that Hubble would be lucky to accomplish 50 percent of its primary goals with the bad mirror.

Fortunately, NASA designed Hubble so astronauts could service it. And engineers were able to examine the Hubble images and precisely characterize the mirror's flaw. Back on the ground, the teams who built future Hubble instruments incorporated corrective optics into their designs. The fixes worked, and Hubble started performing up to specs after the first servicing mission in December 1993.

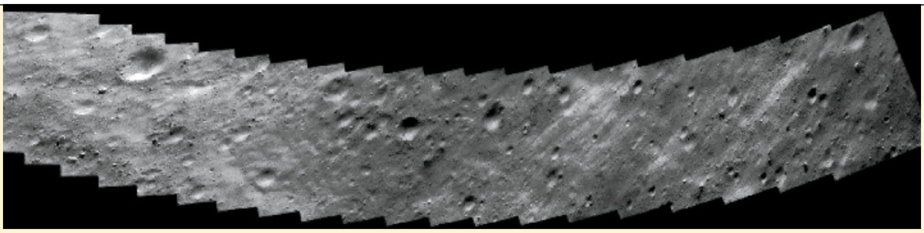
To summarize the science Hubble has produced reads like the history of astronomy during the past 2 decades. It nailed down the universe's expansion rate, discovered dark energy and its role in accelerating this expansion, proved that black holes exist and that supermassive ones lurk at the centers of most large galaxies, and showed that most big galaxies evolved from smaller structures. If all goes well, Hubble should continue to supply extraordinary science and stunning photographs for the next several years.

A pillar of creation in the Eagle Nebula harbors several newborn stars still cloaked by the thick gas and dust from which they formed. Hubble has taken tens of thousands of similarly stunning photos. NASA/ESA/Hubble Heritage Team (STScI/AURA)

would fly by Eros instead. It passed 2,380 miles (3,830 km) above the asteroid's surface December 23. The spacecraft's camera snapped 222 pictures as it went.

But mission planners had a trick up their sleeves. They fired the main engine again January 3, and this time it performed flawlessly. NEAR Shoemaker nearly matched Eros' speed, and during the next 13 months, it crawled back toward the asteroid. On February 14, 2000, the spacecraft finally rendezvoused with Eros and went into orbit.

For the next year, NEAR Shoemaker studied and mapped Eros' surface at a resolution far greater than any previous mission to an asteroid had achieved. The camera snapped more than 160,000 images and revealed a network of fine fractures crisscrossing the surface. Rocks as big as a city block and as small as a large dog dot the landscape. Landslides in some craters exposed fresh material.



A low-altitude flyby of Eros by NEAR Shoemaker reveals rocks of all shapes and sizes strewn over a gently rolling surface. The smallest rocks in this mosaic are just 5 feet (1.4 meters) across. NASA/JHUAPL

On February 12, 2001, mission controllers landed NEAR Shoemaker on the surface. Just before it touched down, the camera returned an image showing details as small as 0.4 inch (1 cm) across. To everyone's surprise, the spacecraft survived the landing and continued returning data until February 28.

In the end, NEAR Shoemaker accomplished all the goals scientists had set for it. Like the other missions on our list, it didn't have an easy time. But inventive people made them all successes. Without these five spacecraft, astronomers would have a poorer understanding of the universe and how it works. ◑

Read about the first Hubble Servicing Mission at www.Astronomy.com/toc.

Ask Astro

Astronomy's experts from around the globe answer your cosmic questions.

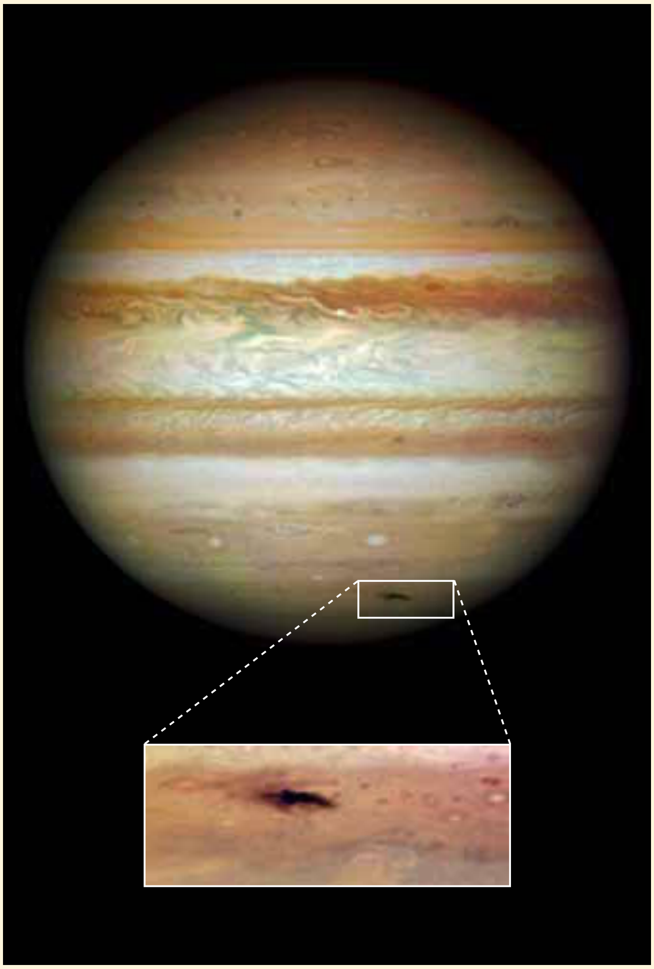
Giant planets bruise, too

Q: Why do impacting bodies on Jupiter leave black splotches even though the gas giant does not have a solid surface? — **Gregg Alliss,** Cedar Rapids, Iowa

A: As an object collides and moves through Jupiter's atmosphere, it compresses the air in front of it — this is called atmospheric ram pressure. The compressed air reaches tens of thousands of degrees, heating the object. The intense heat high in the atmosphere vaporizes a small object (such as a meteor), and leaves no subsequent trace. Amateur astronomers viewed this phenomenon on Jupiter in early June 2010 and again in August 2010.

When a large object collides with Jupiter, however, it penetrates deep into the atmosphere. If the ram pressure is high enough, it rapidly and catastrophically disrupts the object in an explosion. The energy of this blast moves away from the site, mainly along the path of least resistance: the superheated column of gas trailing behind the descending object. In other words, **the explosion blasts out along the trail that the massive meteor created. A huge fireball of heated atmosphere rises high above Jupiter's cloud tops from this superheated column. The fireball's debris rapidly cools into dark jovian "soot" and collapses onto Jupiter's cloud tops, making a characteristic dark impact site.**

The Hubble Space Telescope imaged many impact sites created by the fragments of Comet Shoemaker-Levy 9 in 1994, and even saw the tip of a large fireball before it collapsed onto the cloud tops. Another Jupiter impact occurred in 2009 that was not imaged directly. However, from the dark spot the explosion created, we estimated the body's size prior to its demise to be perhaps as large as 1,640 feet (500 meters). — **Heidi Hammel,** Space Science Institute, Boulder, Colorado



Dark scars on Jupiter, such as this one seen in July 2009, result from large meteors exploding in the planet's atmosphere. NASA/ESA/H. Hammel (Space Science Institute, Boulder, Colorado), and the Jupiter Impact Team

IN THE SHADOW

Q: What causes the variety of totality length from one solar eclipse to the next? Why does the length of totality vary along the path of an eclipse? — **John Carlson,** Colon, Michigan

A: Two primary factors cause the duration of totality to differ from one eclipse to the next. **First, the Moon's distance from Earth varies over its orbit** from the nearest distance, or perigee (average value of 225,804 miles [363,396 kilometers]), to the farthest, or apogee (average value of 251,969 miles [405,504 km]). This 11.6 percent range in distance causes the Moon's apparent diameter (the angular diameter seen from Earth) to fluctuate by the same amount. A larger Moon means it hides the Sun longer during a total eclipse.

Second, Earth's elliptical orbit causes the Sun's distance and apparent diameter to vary by about 3 percent from perihelion (closest approach) to aphelion (farthest approach). This too affects the duration because a smaller Sun is eclipsed longer. So the longest total eclipses occur when the Moon is near perigee and Earth is near aphelion. These exact circumstances were responsible for the long totality during the solar eclipse July 22, 2009.

The length of totality also varies along the path of any one eclipse. The Moon's umbral shadow sweeps out a path across Earth, beginning at the sunrise terminator, passing through the midday meridian, and ending at the sunset terminator. **Near the sunrise and sunset terminators, the Moon's shadow hits Earth's surface at a steep angle. This geometry causes the shadow to move quickly with respect to the surface, which shortens totality's duration.**

In comparison, the angle of the Moon's shadow is less steep as the eclipse path crosses the midday meridian. Furthermore, Earth's surface rotates in the same general direction as the motion of the Moon's shadow. Although the shadow moves faster, Earth's rotation partially compensates for its motion and prolongs totality.

Of course, other less important factors affect eclipse duration, such as the season (produced by the axial tilt of Earth with respect to the Sun), the inclination of the Moon's orbit to the celestial equator, the geographic latitude of the eclipse path, and the curvature and flattening of Earth's surface. — **Fred Espenak,** NASA's Goddard Space Flight Center, Greenbelt, Maryland

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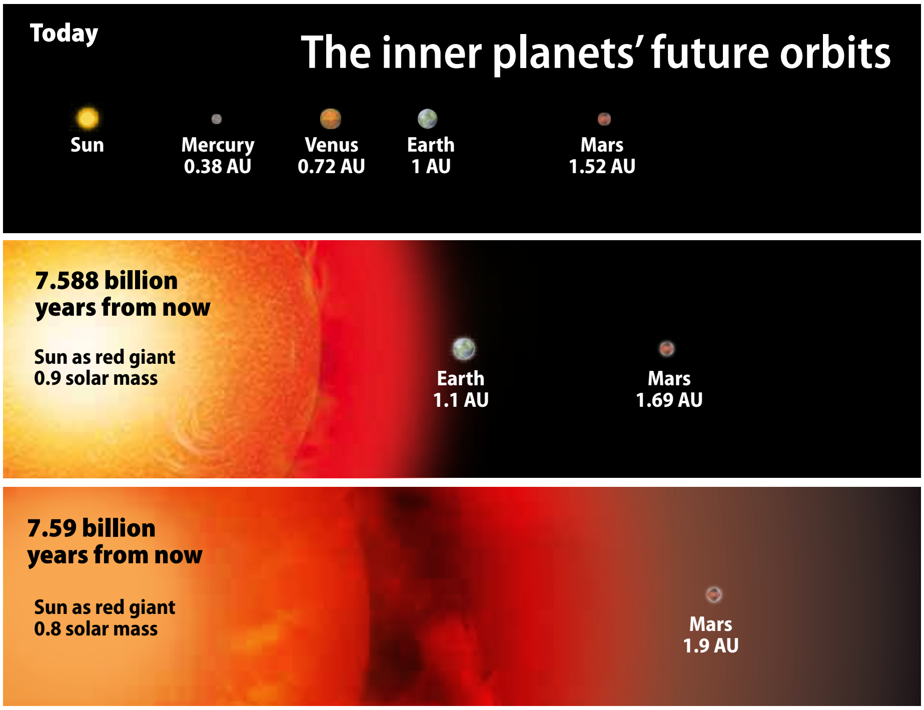
WILL EARTH ESCAPE?

Q: At the end of the Sun's life, when it expands into a red giant, what will become of the planets in the solar system? — **Matt Pearson,** Mildura, Australia

A: The final act of a Sun-like star begins when it becomes a red giant — a bloated object with a lower surface temperature that emits lots of gas and dust. **No one knows exactly what will happen to all the planets because we have yet to observe an entire planetary system experiencing this kind of stellar evolution.** But astronomers have some good ideas based on introductory physics — namely gravity and tides.

Let's start with gravity. As our star's life ends, it will swell to more than 200 times its size, extending its surface beyond the Earth-Sun distance. At the same time, it will blow away much of its mass in a steady wind. In fact, the latest calculations of the Sun's evolution billions of years from now suggest that it will have lost about a third of its mass when it reaches its largest size.

What is Pluto's temperature? Find out at www.Astronomy.com/toc.



The Sun will grow larger and extend beyond Earth's current orbit (an astronomical unit, or AU). Our star will also blow away mass in a steady wind. So our planet's orbit will expand and Earth should be safe — until the Sun's gravitational tides pull it in. *Astronomy*: Roen Kelly, after Klaus-Peter Shroeder and Robert Cannon Smith

Although the red giant will be losing mass, it won't send the planets spinning off into space because it's happening extremely slowly compared to any planet's orbit. So the planets gradually expand their orbits in response to the smaller mass pulling on them. It becomes a race to see whether each planet's orbit increases beyond the expanding radius of the red giant. **At the Sun's largest size, all of the planets will have expanded their orbits by about 1.5 times — Mercury and Venus definitely will lose the race, but Earth should remain just outside the Sun's surface.**

It seems that Earth should be safe. However, just as the Moon tugs on Earth to create tides in the oceans, a planet can raise tides on the Sun. **They steal energy from the planet's orbit, so that over a long enough time, the Sun's tides suck in the world. Unfortunately, that's probably what will happen to Earth.**

As for the giant planets, not much seems to affect them in this scenario. The change in gravity, the red giant's wind, and the Sun's tides won't be strong enough to pull the gas giants into the star's embrace. They'll survive even beyond when our star becomes a white dwarf. — **John Debes,** NASA's Goddard Space Flight Center, Greenbelt, Maryland

RING AROUND THE BLACK HOLE

Q: What happens to dark matter in the gravity field of a black hole? — **J.C. Chauveau,** Le Mesnil-Saint-Denis, France

A: Dark matter interacts via gravity, so it will orbit a black hole like any other particle — just like everything in the solar system revolves around the Sun. Occasionally, dark matter particles can get knocked onto paths that cause them to fall directly into the black hole. So that black hole is made partially of dark matter.

But most of a black hole's mass comes from normal matter like electrons and protons falling in, not dark matter. This is because normal matter in orbit around a black hole can feel frictional forces that cause it to fall in rapidly. Dark matter doesn't interact via the electromagnetic force, and therefore doesn't experience friction. Hence, **most of the time, dark matter particles simply orbit around the black hole rather than falling in.** — **Eliot Quataert,** University of California, Berkeley

Send your questions via e-mail to: **askastro@astronomy.com**; or write to **Ask Astro, P. O. Box 1612, Waukesha, WI 53187**. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

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Stellar observing

See the nearest stars

The stars next door are fun to hunt, easy to spot, and can teach you about astrophysics.

text by Michael E. Bakich; astroimages by Anthony Ayiomamitis

Three decades ago, I set as a goal identifying both the 100 brightest stars and the 100 nearest stars. As you might imagine, the first list was easier to finish than the second, which I'm still not done with. I've yet to observe number 48 on the latter list, DEN 0255–4700. Perhaps its magnitude — 22.9 — has something to do with that.

But let's not dwell on what we can't see. Here, I want to introduce you to a few highlights on the list of the 100 nearest stars. I think you'll find, as I did, that the Sun's closest neighbors are not only a fascinating group, but that they also have taught us a lot about astronomy. In pursuit of the 100 nearest stars, I encountered some of the most famous of the sky's luminaries. I offer this story to encourage you to do the same.

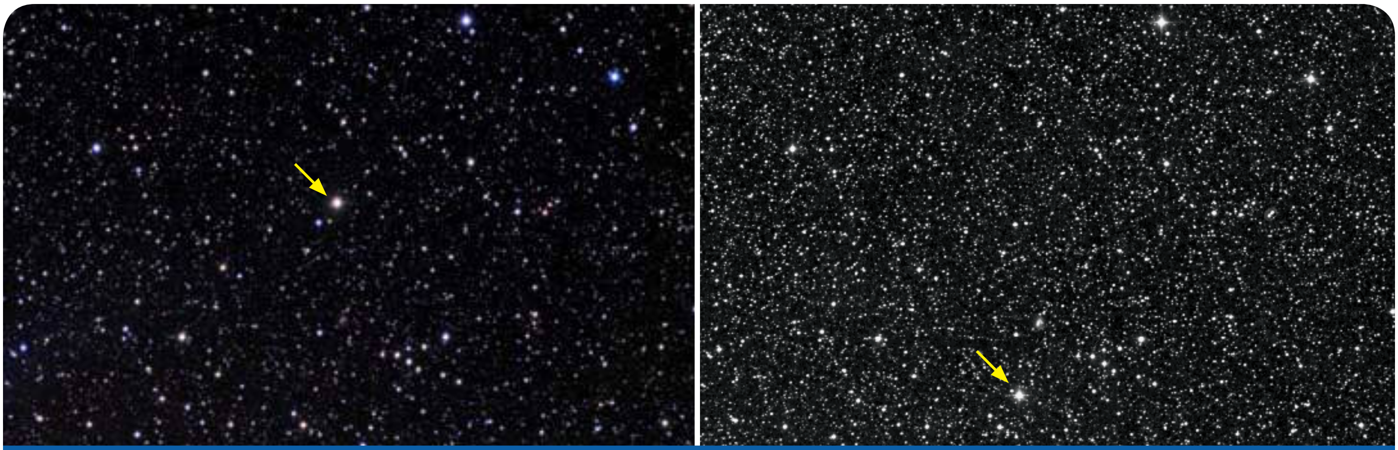
Using an 8-inch telescope from a dark site, you should be able to catch nearly 90 of the 100 nearest star systems. Four of them are among the top 12 brightest stars, and you can see 14 more without optical aid. Surprisingly, only seven of the systems lie south of declination –50°. Realistically, then, the other 93 are visible from latitude 35° north — great news for Northern Hemisphere observers. How many of them can you spot? To help you with your search, we've also placed a PDF file of all 100 star systems on our website at www.Astronomy.com/toc.

Number 1 — Alpha Centauri

With the possible exception of the North Star (Alpha [α] Ursae Minoris), the first star name most schoolchildren learn is Alpha Centauri — the closest star to Earth. But that's a general description. In reality, Alpha Centauri is a triple star.

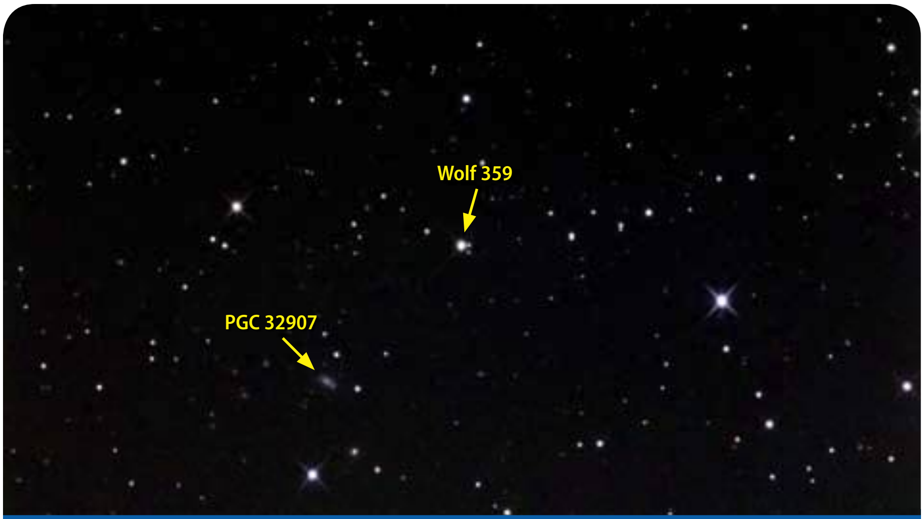
The two brightest components, which astronomers designate as A and B, combine to form the sky's third-brightest "star." Alpha Centauri A shines at magnitude 0.01, and B isn't far behind at magnitude 1.34. Together, this adds up to magnitude –0.29. The separation between the two stars varies between about 2" and 23". In 2010, it stands at 7", so even the smallest telescope will split the pair. A and B tie for second place among closest stars to our Sun — 4.36 light-years away.

But it's the third component, Alpha Centauri C, that reigns as the closest star to Earth. It lies more than 2 percent closer at 4.24 light-years away. Unfortunately, this dim bulb glows meekly at magnitude 11.1, but it's worth the effort it will take for you to identify it.



Barnard's Star ranks as the second-closest star system to Earth. It also tops the list as the star with the largest proper motion. Compare its 2010 position (left image) to the position it occupied in the 1950s when astronomers at Palomar Observatory photographed its region of sky. In the intervening 50-plus years, the star's motion across the sky equals 10', almost one-third the diameter of the Full Moon. To find Barnard's Star, look 0.7° west-northwest of the magnitude 4.8 star 66 Ophiuchi.

Right-hand image: National Geographic Society–Palomar Observatory Sky Survey



Wolf 359 derives its designation from German astronomer Maximilian Franz Joseph Cornelius Wolf, who discovered this nearby star in 1918. You'll need a large telescope at a dark observing site to spot this pale ember's magnitude 13.4 glow. You'll find it 0.8° north of the magnitude 5.9 star 56 Leonis. While you're in the area, try to spot spiral galaxy PGC 32907. This ultra-faint star system glows at magnitude 15.6 and lies 8.5' south-southeast of Wolf 359.

Lalande 21185 sits 2.3° south of the magnitude 6.0 star 51 Ursae Majoris. At magnitude 7.5, the fourth-nearest star system is an easy catch through binoculars from a dark site. Joseph Jérôme Lefrançois de Lalande discovered this red dwarf in 1801. It sits 8.3 light-years from Earth. Lalande 21185 ranked as the second-closest star system from its discovery until 1916, when Barnard's Star took over that position.

Number 2 — Barnard's Star

This star in Ophiuchus may rank as the second-closest system, but it ranks number one as far as proper motion goes. This number measures the apparent movement of a star — in arcseconds per year — across our line of sight. In 1916, American astronomer Edward Emerson Barnard measured this value for V2500 Ophiuchi to be 10.3". Because it attained fame as the fastest-moving star, everyone has called it Barnard's Star since.

This magnitude 9.5 red dwarf lies only 5.96 light-years away. With a luminosity of 0.0004 times that of the Sun, this is one faint star. It's also old. Scientists peg its age at 11 or 12 billion years — more than twice as old as the Sun.

Number 3 — Wolf 359

I'll bet many of you watched the original *Star Trek*. I'll also bet most of you don't know that in that series Wolf 359 was the star around which Mr. Spock's home planet, Vulcan, revolved. That wasn't a bad choice considering the star sits only 7.8 light-years from Earth.

You'll need at least an 8-inch telescope and a dark observing site to spot this pale red dot in Leo. Wolf 359 glows at magnitude 13.4. It has a mass of approximately 9 percent that of the Sun — barely enough, in fact, to qualify it as a star. Indeed, Mr. Spock's Vulcan would have needed to orbit ultra-close to this subluminary to receive enough energy to keep its civilization going.

Number 4 — Lalande 21185

Shining 230 times brighter than Wolf 359, Lalande 21185 in Ursa Major glows at magnitude 7.5 and lies 8.3 light-years away. This star's designation comes from its position (out of 47,390 stars) in the 1847 edition of French astronomer Joseph Jérôme Lefrançois de Lalande's star catalog, *Histoire Céleste Française*.

All stars move through space in various directions, but Lalande 21185's motion is carrying it closer to Earth. In 19,500 years, it will supercede both Wolf 359 and Barnard's Star. At that time, its distance will be 4.66 light-years, only about two-fifths of a light-year farther away than Alpha Centauri C.

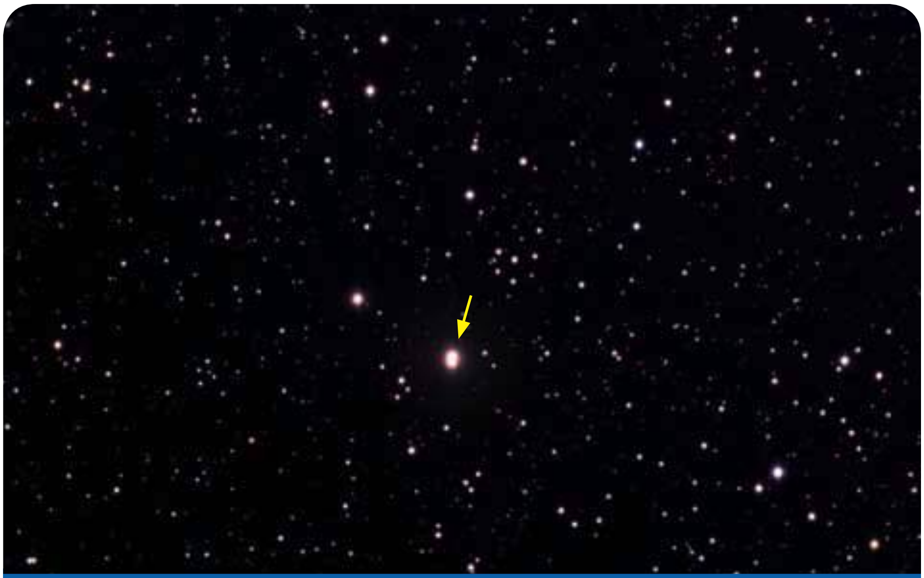
Number 7 — Ross 154

In 1925, American astronomer Frank Elmore Ross compiled his fourth list of newly discovered variable stars. This one in Sagittarius was number 154. Astronomers classify it as a flare star, V1216 Sagittarii. During an outburst, the star's brightness may increase by 4 magnitudes. Normally, it is a red magnitude 10.4 star, and it lies 9.7 light-years away.

Ross 154 is an example of a flare star, one that undergoes large, unpredictable short-duration increases in brightness. It lies 1.5° southwest of magnitude 4.9 Nu^1 (ν^1) Sagittarii. Ross 154 normally glows at magnitude 10.4. Luckily, no similarly bright star is in its immediate area, so you won't have trouble identifying it through a 4-inch or larger telescope.

Michael E. Bakich *is an* Astronomy *senior editor.* **Anthony Ayiomamitis** *is a full-time astroimager who lives in Athens, Greece.*

61 Cygni is a bright double star with components of magnitude 5.2 and 6.0. The pair sits in a heavily populated region of the Milky Way in Cygnus. In 1804, Italian astronomer Giuseppe Piazzi discovered 61 Cygni had a large proper motion (5.2"/year) and christened it the Flying Star.



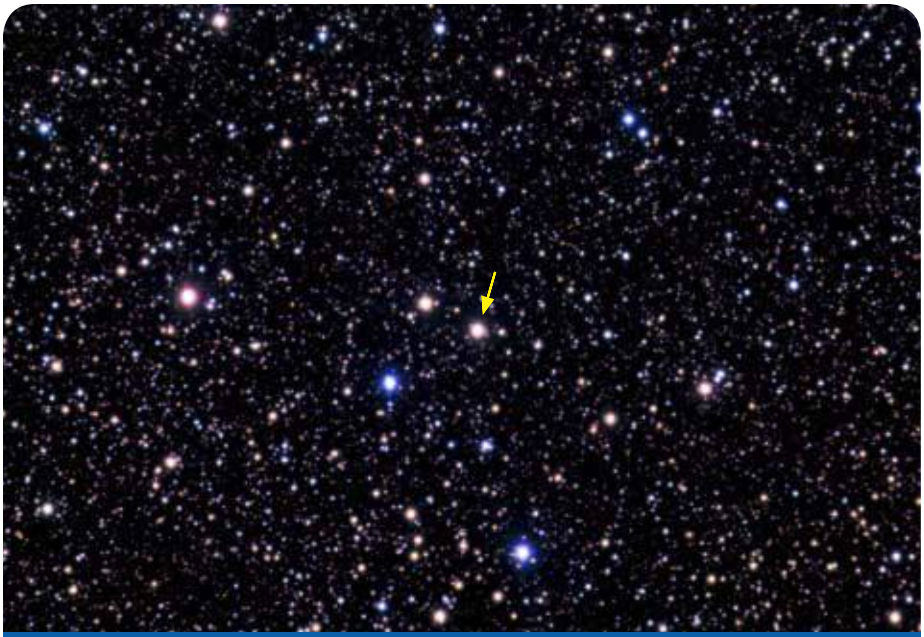
LFT 1431 and LFT 1432 constitute a double star in Draco. To find it, look 1.1° west-northwest of magnitude 4.6 Omicron (ο) Draconis. This system reveals itself easily through a small telescope because it's the only binary star in the field of view. A 3-inch or larger scope at a magnification of 75x or higher will split this 14"-wide pair of reddish suns.

Ross 154 contains 17 percent of the Sun's mass and is only one-quarter as large. This star is a moderately fast rotator, spinning at about 2.2 mph (3.5 km/hr). Because of this characteristic, stellar physicists think Ross 154 is less than 1 billion years old.

Number 14 — 61 Cygni

Most observers can see this next entry, 61 Cygni, without optical aid from a dark observing site. This double star has a primary that shines at magnitude 5.2, and the secondary isn't far behind it. At magnitude 6.0, 61 Cygni B has 48 percent the light output of component A. This pair sits 11.4 light-years away.

German astronomer Friedrich Wilhelm Bessel cemented 61 Cygni's place in astronomy history by making it the first star to have its parallax measured, which occurred in 1838. Stellar parallax is the apparent shift of a star's position (measured against much farther background stars) as Earth moves from one side of its orbit to the other.



Kruger 60 A and B appear as a single star in this image, but the system is really a pair of red dwarfs. Look for it 44' south-southwest of magnitude 4.1 Delta (δ) Cephei. A small telescope will split this pair, revealing the A component shining 2.1 times brighter than the B star.

Number 15 — LFT 1431–32

LFT 1431 is a double-star system in Draco that lies 11.5 light-years away. The brighter primary shines at magnitude 8.9, almost exactly twice as bright as the magnitude 9.7 secondary LFT 1432. Both stars glow with a reddish light. The separation between the two is 14", so even a small telescope will split this pair.

Oh, and if you've never heard of the designation "LFT," I understand. This three-letter acronym is astro-shorthand for Dutch-American astronomer Willem Jacob Luyten's *A Catalog of 1849 Stars with Proper Motion exceeding 0.5" annually*. Because the catalog lists stars with proper motions exceeding five-tenths of an arcsecond, the abbreviation stands for "Luyten Five-Tenths." Luyten also compiled the catalogs LTT (Luyten Two-Tenths) and LHS (Luyten Half-Second).

Number 27 — Kruger 60 A and B

At a distance of 13.14 light-years, the double star Kruger 60 is a pair of red dwarfs in the constellation Cepheus. The stars glow at magnitudes 9.8 and 11.4. Because the secondary star orbits the primary once in a little more than 44 years, the separation between the two varies between 2" and 3". Those numbers work out to actual distances equaling the separation between the Sun and Jupiter and the Sun and Saturn, respectively. In either case, you'll resolve the duo easily through a 4-inch or larger telescope.

Like Ross 154, Kruger 60 B is a flare star. This object undergoes a huge increase in brightness over a short interval of time. Consider yourself incredibly lucky if you see (or even image) Kruger 60 B in outburst. The star doubles its light output and then returns to normal during an 8-minute span. Unfortunately, it does this on an irregular basis.

Number 52 — 70 Ophiuchi

Our next target is another double star, but — with a separation of 5" — this one's a bit harder to separate than LFT 1431. Still, it makes an easy target for small scopes, and it's a showpiece object for summer double-star observers.

The brighter star, 70 Oph A, gives off a yellow-orange light with a magnitude of 4.2. Its companion, 70 Oph B, at magnitude 6.1, emits only 17 percent as much light. The brightness of this pair means you can see 70 Ophiuchi as a single point of light without optical aid from a dark site, and any scope will split the pair. The two stars lie 16.6 light-years from Earth.

German-born English astronomer Sir William Herschel discovered the binary nature of 70 Ophiuchi in 1779. He also mentioned that a possible unseen third star was affecting the orbits of the other two. In 1855, William S. Jacob, director of the Madras Observatory in India, noted an anomaly in the orbits of the two visible stars he attributed to a planet. His claim — since proven erroneous — was one of the first for an exoplanet based on measured evidence.

70 Ophiuchi may look like a single star in this image, but it's actually a close binary star. The separation, 5", is an easy split through a small telescope. To most observers' eyes, both components have an orange hue, with the brighter one a bit on the yellow side.

Altair, at magnitude 0.77, is one of the sky's brightest stars. You can spot it in the evening sky from most of Earth's surface throughout the Northern Hemisphere's summer and fall. When you do, you're seeing light that's been traveling from that star for less than 17 years.

Number 53 — Altair

I'll finish with a brief description of the 12th-brightest star, magnitude 0.77 Altair (Alpha Aquilae) in Aquila the Eagle. It lies 16.7 light-years from Earth.

As one of the closest — and brightest — stars, astronomers have discovered many details about Altair. For example, it rotates so rapidly (once in 9 hours, compared to the Sun's 25 days) that its equatorial diameter swells 20 percent more than its polar diameter. Infrared observations by the Palomar Testbed Interferometer in 1999 confirmed this swelling.

The name Altair, or some variant of it, has referred to an eagle since ancient Mesopotamian times. Planets around Altair have been featured in several episodes of the *Star Trek* television series, and the imagined fourth planet from this star was the setting for the 1956 sci-fi classic *Forbidden Planet*.

Download a PDF file listing the 100 closest stars at www.Astronomy.com/toc.

A worthy challenge

Spotting a large percentage of the 100 nearest stars will take time and maybe some travel, if you want to spot the far-southern entries. Along the way, you'll encounter really bright and really faint stars, colorful doubles, and other luminaries famous for a variety of reasons.

Take your time, be certain of your identifications, and by all means read about the history and science of each of our nearest neighbors in space.

PlaneWave's hot new astroimaging scope

The new CDK17 telescope offers thermal stability, ease of use, and killer images. **by Tony Hallas**

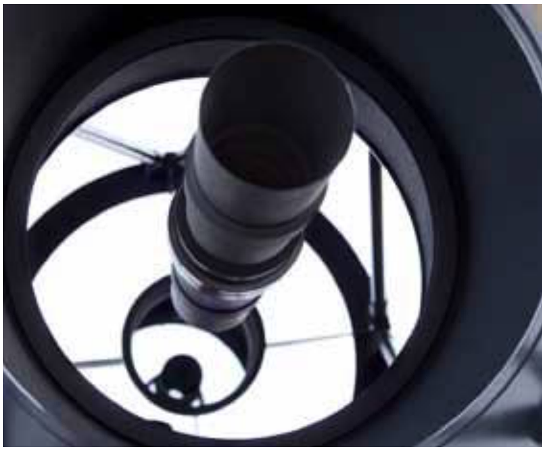
What happens when a group of dedicated astronomers pool their talents to create a new company? You get the products of PlaneWave Instruments.

A few years ago, company founders Richard Hedrick and Joseph Haberman, former telescope engineers at Celestron, got together with optician Dave Rowe and worked out a new telescope design using simple optics that offers superlative performance. Their company now offers Dall-Kirkham telescopes in 12.5-inch f/8, 17-inch f/6.8, and 20-inch f/6.8 versions. As I write this, 24- and 28-inch versions are in the works.

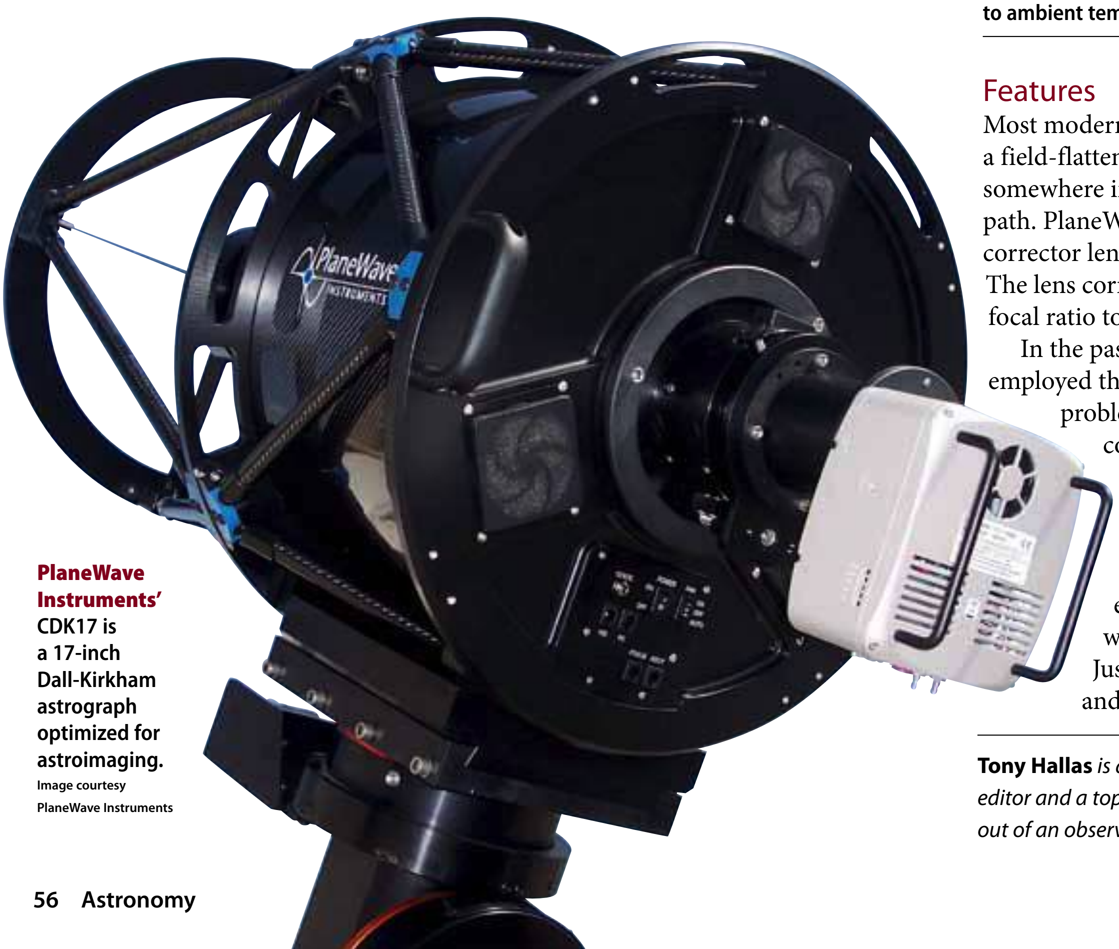
For this review, I tested the CDK17, PlaneWave's 17-inch f/6.8 model. The "CDK" stands for "corrected Dall-Kirkham" design, by the way. I placed it atop an Astro-Physics 1200 GTO mount in my backyard observatory.

This model came with a quartz primary mirror rather than the Pyrex one the company normally installs in its scopes. Haberman informed me that the company will offer quartz primaries as an option from now on.

Quartz has superior thermal stability and doesn't expand or contract with temperature changes. This means you don't have to refocus as the night air cools. Quartz also conducts heat well, so the mirror cools to ambient temperature quickly and completely. I strongly recommend that you opt for quartz.



The primary mirror in the CDK17 starts with a focal ratio of f/2.6. Adding the secondary mirror and a two-element corrector lens brings the telescope's focal ratio to f/6.8. Behind the primary, three cooling fans help bring the optics to ambient temperature. Tony Hallas



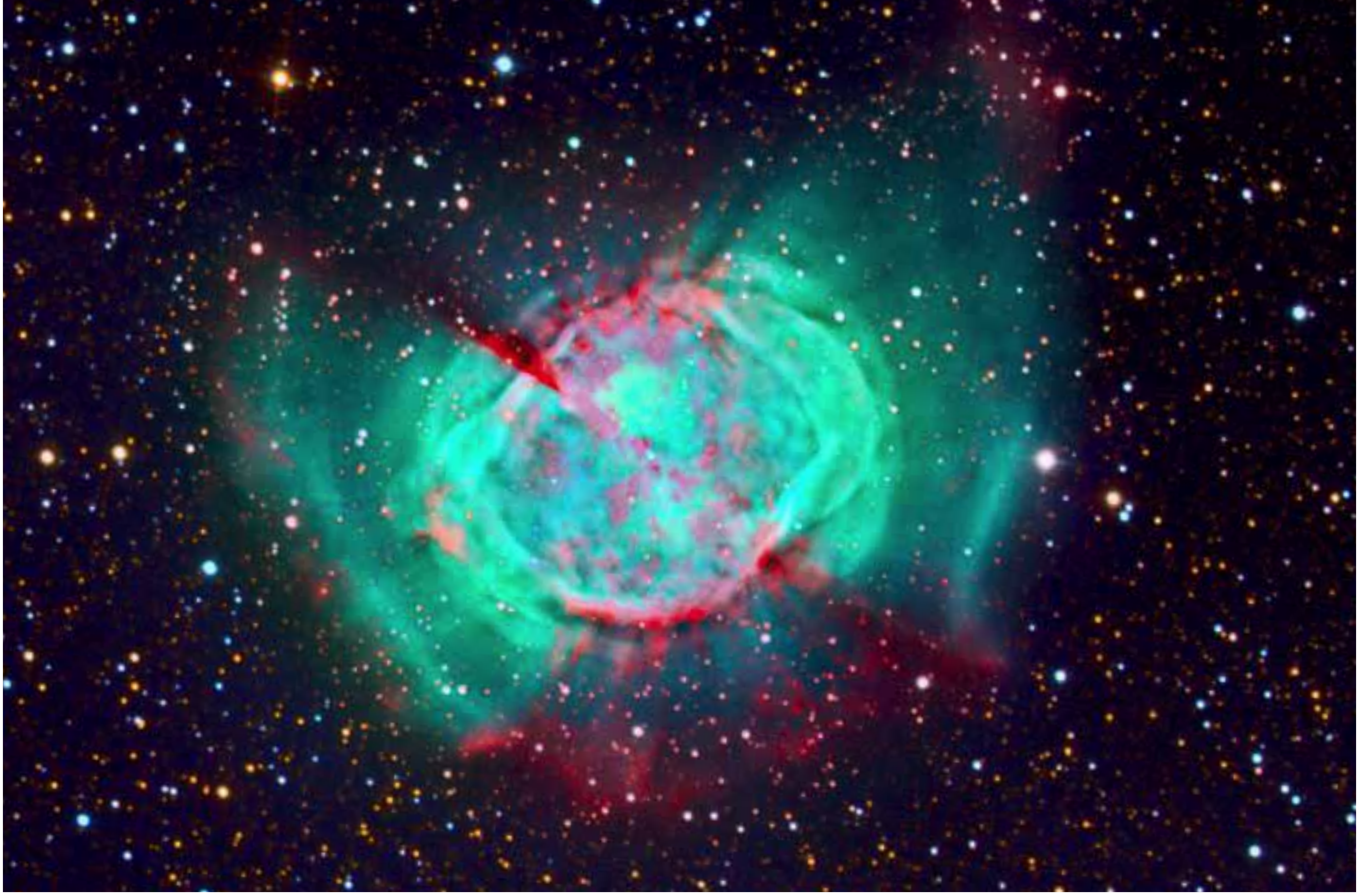
PlaneWave Instruments' CDK17 is a 17-inch Dall-Kirkham astrograph optimized for astroimaging. Image courtesy PlaneWave Instruments

Features

Most modern Cassegrain reflectors have a field-flattening lens assembly installed somewhere in the telescope's imaging path. PlaneWave utilizes a two-element corrector lens in the primary baffle tube. The lens corrects the field and brings the focal ratio to f/6.8.

In the past, other telescopes that employed this design had a persistent problem. It was tough to keep the corrector lens clean in the baffle tube. Anything — like dust — that fell down the tube ended up on the lens. PlaneWave made it easy to get to the lens group when you need to clean it. Just unscrew the baffle tube, and out comes the lens.

Tony Hallas *is an* Astronomy *contributing editor and a top-notch astroimager who works out of an observatory in Foresthill, California.*



The Dumbbell Nebula (M27) shows lots of nebulous detail and sharp stars to the edge of the field of view in this test image the author took. Tony Hallas

The telescope's upper and lower cages both utilize a carbon fiber surrier truss design. The primary mirror has a carbon fiber light baffle and three vibration-free fans to cool it. PlaneWave also builds a heater into the secondary mirror holder to keep the dew off on those wet nights.

The user can control the telescope via a hand paddle or remotely. Setup is simple because the secondary mirror is part of a sphere, and its centering is not critical. PlaneWave permanently fastens the primary mirror in its cell and collimates it at the factory. You will need only to collimate the secondary mirror — a simple procedure using any star.

I also appreciated the new giant focuser the company uses on this telescope. I found it absolutely flat to the image plane. And soon PlaneWave will add a rotator to the focuser assembly. It may be an available option by the time you read this.

Standout performer

I was impressed with the images I took through the CDK17. Each reveals sharp stars corner to corner on a giant 40mm by 40mm 16803 CCD chip. Even when I positioned the telescope upside down to shoot west of the meridian, the stars remained perfectly focused.

A telescope should be a pleasure to use, and this one was. All imagers want to create the best, and the PlaneWave CDK17 will not disappoint you. If a picture is worth a thousand words, one look at the star field I shot through the CDK17 is all you need to realize that this telescope is special.

The massive focuser PlaneWave chose for its 17-inch telescope is a 3.5" Hedrick heavy-duty, no-slip model. A leadscrew drives the tube, which rides on five bearings. The drawtube travel is 1.3 inches (33 millimeters). Tony Hallas

Product specifications

PlaneWave CDK17 optical tube assembly
Type: Corrected Dall-Kirkham astrograph
Aperture: 17 inches
Focal ratio: f/6.8
Focal length: 2,939 millimeters
Weight: 94 pounds (42.6 kilograms)
Length: 37 inches (940mm)
Focuser: 3.5" Hedrick heavy duty
Included: 3.5"-to-2" adapter, primary mirror cover, 12-volt DC power supply, Ronchi spacer and ocular
Price: $22,000

Contact information

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Torrance, CA 90501
[t] 310.787.9411
[w] www.planewave.com

EveningStars

by David H. Levy

Camp to the stars

As a crowd of youngsters gets excited about astronomy, it's impossible not to feel the same enthusiasm.

Wendee Levy, the author's wife, enjoys the setting Sun with a group of campers using the McMath-Pierce Solar Telescope at prime focus. David H. Levy

The idea of an astronomy camp is hardly new. Over many years, a number of opportunities have cropped up for youths to get out of town and enjoy a dark sky, but none can approach the magic of the University of Arizona's Astronomy Camp, which this June completed its 23rd season. I only wish I'd had the opportunity to use a mighty telescope atop Kitt Peak in my youth some 45 years ago!

But that was a different time; in those days, I was limited to a portable 3½-inch reflector and a pier-mounted 6-inch refractor at our local observatory. At least now I have the privilege of helping to guide this generation's brightest youngsters, who have the opportunity of using some of the world's best telescopes located under what may be the darkest conditions in North America.

Take the Bart Bok Telescope, for instance, a magnificent 40-year-old instrument. (Campers enjoyed reading an article describing its colorful history in the July issue of *Astronomy*.) One of the larger telescopes on Kitt Peak, its optical quality is superb. It's hard to imagine how a group of teenagers could gain control of such a telescope for several nights.

They would have to go through the traditional process of applying to Steward Observatory's Telescope Allocation Committee at the University of Arizona. It assigns telescope time for all observers and divides that time among the university-owned telescopes. The fact that these campers' proposals were sucessful attests to their scientific merit, but it also supports the innovative idea of allowing young people to use a big telescope, inspiring them to learn about the process of astronomy. Such an achievement is invaluable in helping youngsters understand how scientists really work.

Astronomy Camp is far more than just getting to use Bart Bok's 90-inch (2.3 meters) scope. The campers also enjoyed time on one of Kitt Peak's oldest and most venerable scopes, the McMath-Pierce Solar Telescope, which opened in 1962.

It was while the students used that facility that my wife, Wendee, and I showed up. With the Sun low in the west, we encountered a solar image almost a yard wide; it was bereft of all but two small sunspots, at least in this white light. But as the Sun sank lower, the preceding edge became a reddish hue as its light traveled through more of Earth's atmosphere, while the following side developed a greenish tinge.

Now I understood what I had heard long ago, when observers claimed to see a long-lasting green tinge in the McMath prime focus image. With the unaided eye, the effect lasts just a split second as the last solar rays set, and thus it's called the "green flash." But through the great Kitt Peak solar telescope, the green tinge is a relaxed phenomenon that lasts at least 15 minutes!

With the onset of twilight, Wendee, Camp Director Don McCarthy, and I headed to the 90-inch. The spectrograph was the instrument of choice that night, with an eyepiece available for direct viewing. In my brief presentation to the campers and staff, I compared witnessing the exquisite view through this telescope to the feeling that observers enjoy the world over at the start of each new observing session.

We began with a good look at Saturn — its edge-on rings across the distant world — before slewing the telescope to the position of my latest discovery, 19th-magnitude Comet Jarnac (P/2010 E2). Through the eyepiece, a bright star shone near the center of the field of view. Just off from that star, at the field center, we occasionally glimpsed a faint structure that might have been the comet.

If these experiences sound like something you, or someone you know, would like to be a part of or just learn more about, visit www.astronomycamp.org. Working with these committed, interested young people is always such a thrill. Some of them want careers in astronomy; others are just curious about observing under a dark sky. What unites them all is the thought that after the Sun sets each evening, the boundless eternity of the night sky awaits them.

Browse the "Evening Stars" archive at www.Astronomy.com/Levy.

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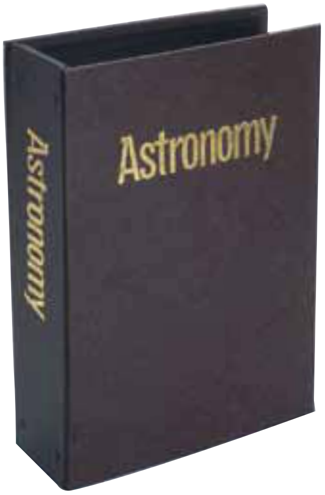

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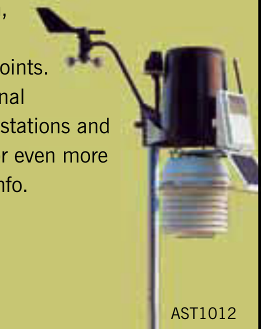

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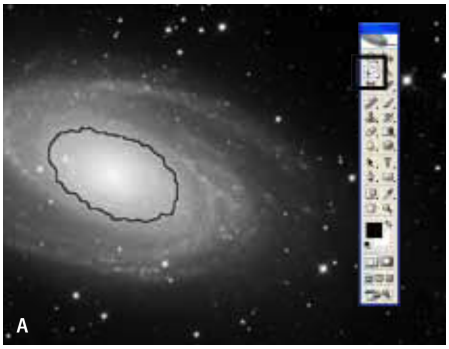
ImagingtheCosmos

by Tony Hallas

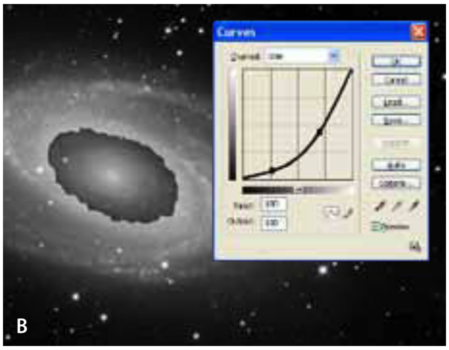
Stretching your data, part 2

If you process your image carefully, you won't leave traces of what you did.

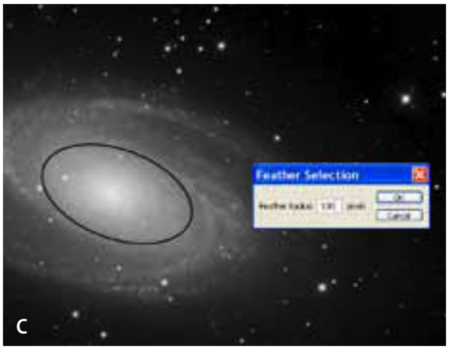


All images: Tony Hallas

While stretching your data, part of your astroimage may become too bright. If so, you need to select that area and darken it.



If you only darken the region you selected, however, others will notice the boundary between it and the rest of the image. Here's where the technique of feathering comes in.

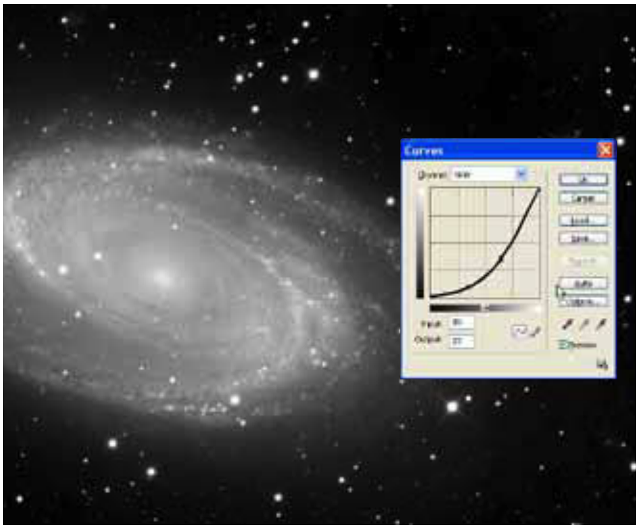


The number of pixels over which you choose to feather the region you selected will determine how gradually the darkening you applied will occur. Hallas chose to feather the image here over a 100-pixel span.

Browse the "Imaging the cosmos" archive at www.Astronomy.com/Hallas.

In this column last month, I showed you how to take the raw 16-bit data from your TIFF files and stretch it using the "Curves" function in Adobe *Photoshop*. I also showed you how to reset the black point using "Levels." But you're now at a stage in your processing where the nucleus of Bode's Galaxy (M81) became too bright. In astroimaging terms, it's "burned out."

The art of darkening the nucleus area without leaving a trace requires three steps.



The completed image of Bode's Galaxy (M81) shows no traces of the selective darkening or the feathering process. Note the additional detail the galaxy's central region now contains.

Step one

Use *Photoshop*'s "Lasso" tool to select the area you want to darken (see image A) by drawing a ring around the area that is too hot. Do not, however, simply open "Curves" and drag down on the line to darken this area. Your result would be similar to image B — not very subtle!

Step two

Go back to the original selection that you made with the "Lasso" tool. There is a way to gradate (fade) the boundary so that the darkening progresses gradually from the unselected to the selected area. That way, you will leave little trace of your handiwork. Astroimagers call this process "feathering the selection." This option is available under *Photoshop*'s "Select" menu.

In image C, the dialogue box tells you that you have chosen to feather the selection across 100 pixels. This means that the darkening will progress from zero percent to 100 percent over the space of 100 pixels. When you do this, the darkening happens without a distinct boundary, and thus you leave no hint of your modification.

Step three

Open "Curves" and darken the selected and "feathered" area. Then deselect it to go back and continue stretching the whole image. If the galaxy's nucleus becomes too hot again, repeat the above procedure.

In summation, you stretched the raw 16-bit TIFF data using "Curves" to lighten the image. But when the image becomes overall too light, you have to reset the black point using "Levels" (as I explained in last month's lesson).

By using the "Lasso" tool and feathering the selection, you can choose any area and give it the additional darkening that it needs. Note that as the situation necessitates, you can use this technique to also selectively lighten an area. Just make sure that after either operation you feather the selection to hide your tracks. Good feathering is one of the secrets of advanced *Photoshop* users, and it makes detection of modifications almost impossible.

Next month, we'll explore how to keep the details in your image even if it contains a wide range of brightnesses.

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The Cosmic Grid

All things high, low, weird, and wonderful in astronomy and space science. **by Bill Andrews**

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Surprising science

Massachusetts high school students plan a theoretical NASA mission, only to discover it's real, and they are going on it.

Hanny & the Voorwerp
a community webcomic

Real live comic

Hanny's Voorwerp, the unusual astronomical object discovered through Galaxy Zoo, inspires a collaborative webcomic, even though the name sounds more like a prog rock band.

Hercule Poi-robot

A NASA robot solves a 19-year-old California murder mystery. Can *Law & Order: NASA* be far behind?

KHAAAAAN!
the Musical

Live, from the Enterprise

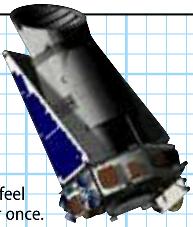
Khaaaaan! The Musical debuts in Kansas City, Missouri, finally providing a dramaturgical refrain to rival "Stellllllaaaaaa!"

Fun in the red sun

Space Telescope Science Institute News Chief Ray Villard writes that red dwarfs might be well-suited for life, though it still feels vaguely offensive when said out loud.

Higgs and the bosons

CERN researchers simulate the sound of the Higgs boson in the Large Hadron Collider. Apparently, it sounds like the end of *2001: A Space Odyssey* looks.



Kepler mouth shut

A high-ranking member of the Kepler satellite mission potentially leaks information to the press, making us at *Astronomy* feel like typical journalists for once.

Heart of darkness

A new study suggests the Sun may have a deposit of dark matter trapped in its core. Hollywood begins rubbing its hands in anticipation …

Good science, funny name

Australia's Commonwealth Scientific and Industrial Research Organisation announces that its astronomers helped find the cause of "dicky tickers." Rival agencies begin combing their spam folders for ideas.

Nemesis, no more

A recent fossil study shows extinction events are too regular for a nearby dark star, often dubbed Nemesis, to be the cause. But with no Nemesis, how will Earth's story keep any dramatic tension?

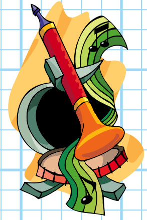
Spacial effects

Blastr.com publishes "The 16 most intelligent sci-fi films ever made," but — crazily — only five have to do with space!

THE LEGEND OF
ZELDA
Skyward Sword

Gaming looks up

Nintendo continues its efforts to popularize space with its recent releases, *Super Mario Galaxy 2* and *Metroid: Other M*. What's next, a *Zelda* game about the skies?



Musical math

Herbie Hancock tells the *Los Angeles Times* the secret to great musicianship is doing your math and science homework. Scientists appreciate it, but parents wish he'd also included eating your vegetables.

ASL on ISS

An astronaut sends the first sign language message from space, leaving NASA engineers struggling to come up with another first for future missions to perform.

Serious gaming

NASA releases a 3-D immersive video game, *Moonbase Alpha*. It's the closest many have come to fulfilling their dreams of becoming astronauts, and the closest I've come to fulfilling my dream of playing video games at work.

Space-o-saurs

British science minister David Willetts says, "The two best ways of getting young people into science are space and dinosaurs." To any alien dinosaurs reading this: practice more outreach!

Check it out ASAP

The Dumb Or Overly Forced Astronomical Acronyms Site (DOOFAAS) provides procrastinators with much fun reading. Personal favorite: GADZOOKS! — Gadolinium Antineutrino Detector Zealously Outperforming Old Kamiokande, Super!

We're robots on the Moon

NASA's "Project M" aims to get a humanoid robot on the Moon in 1,000 days starting 1/1/10. Well, if we can't colonize the solar system, at least our robots can!

Man in the Moon

NASA_Hubble tweets: "The message going around about Hubble finding human remains on the Moon is a joke. Don't take it seriously." Of course, some people will just consider it a cover up.

Boeing 7777?

Boeing continues working on a spaceship to fly people to and from the International Space Station, though they may have trouble finding volunteers for the exit row seats.

Bursting Hubble

The "Hubble Gotchu" guy from *Late Night with Jimmy Fallon*, sad about the space telescope's imminent death, travels to Goddard to try to change their plans. "Webb Gotchu" just doesn't have the same ring to it.

PREDICTABLE

PHOTOGRAPHS: NASA (Surprising science); http://hannysvoorwerp.zooniverse.org (Real live comic); Bryan Colley (Live, from the Enterprise); NASA/ESA/G. Bacon (STScI) (Fun in the red sun); National Institute of Standards and Technology (Higgs and the bosons); NASA (Kepler mouth shut); SOHO-EIT Consortium/ESA/NASA (Heart of darkness); NASA (Nemesis, no more); NASA/GM (We're robots on the Moon); © 2010 Jupiterimages Corporation (Man in the Moon); NASA (Bursting Hubble); Boeing (Boeing 7777?); Nintendo (Gaming looks up); © 2010 Jupiterimages Corporation (Musical math); NASA (ASL on ISS); NASA (Serious gaming); NASA/JPL/Lily Mackay/Noeleen Lowndes (Space-o-saurs)

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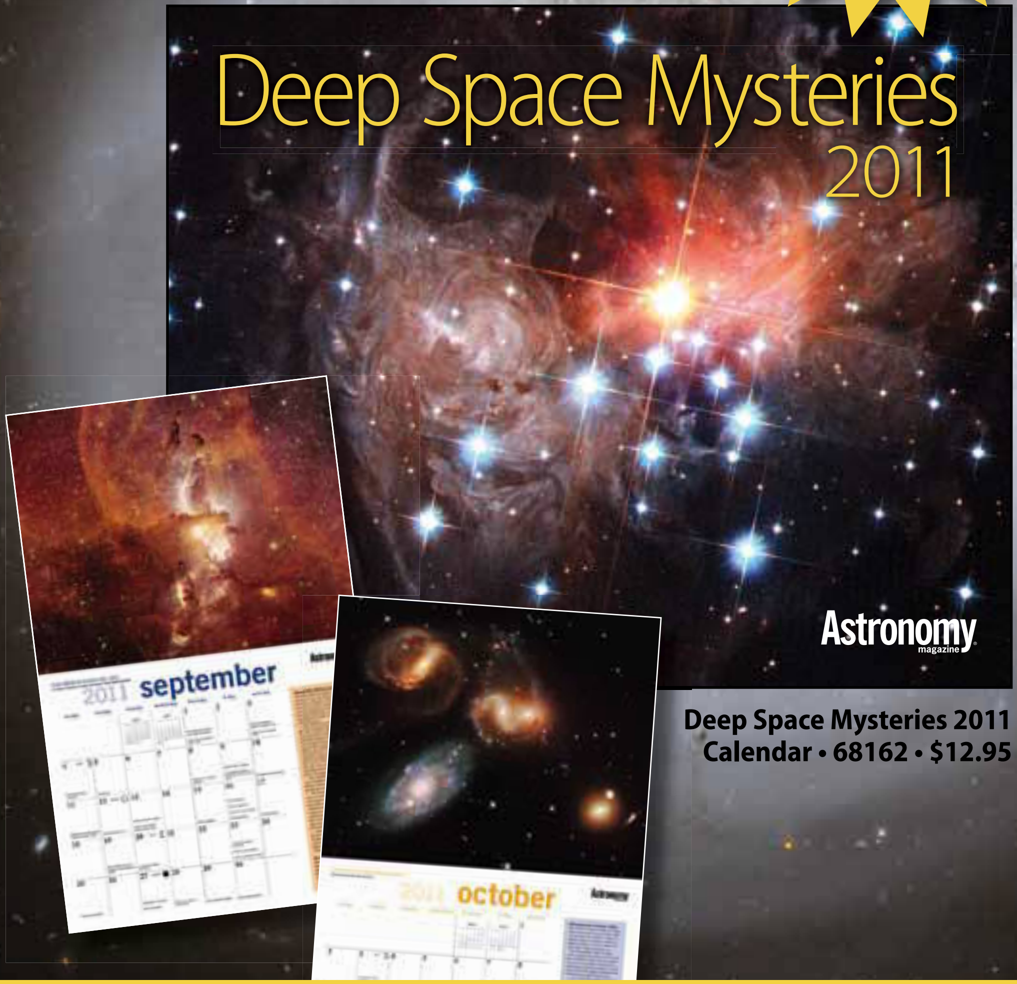
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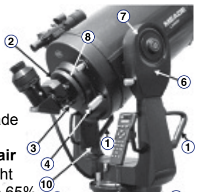

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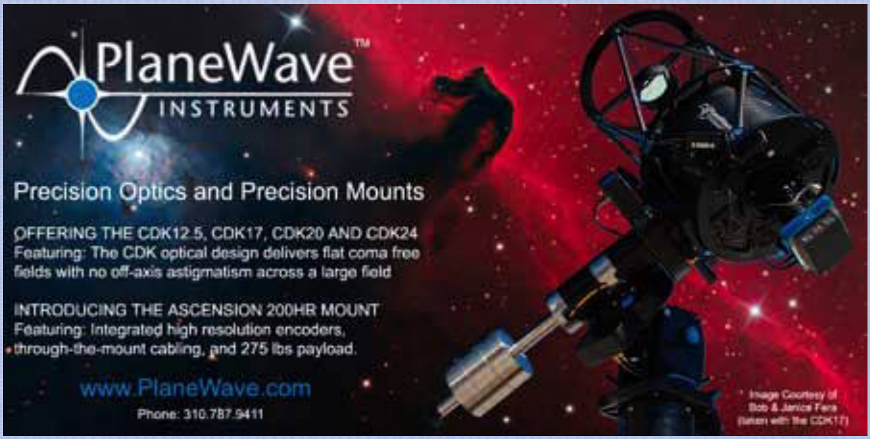
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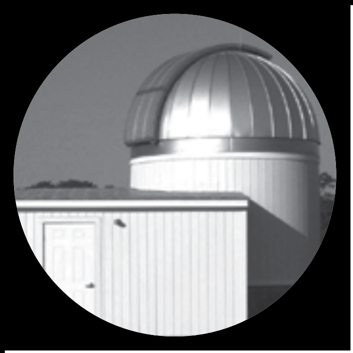
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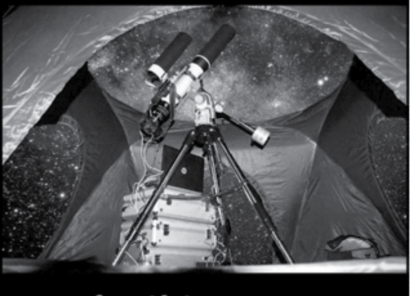

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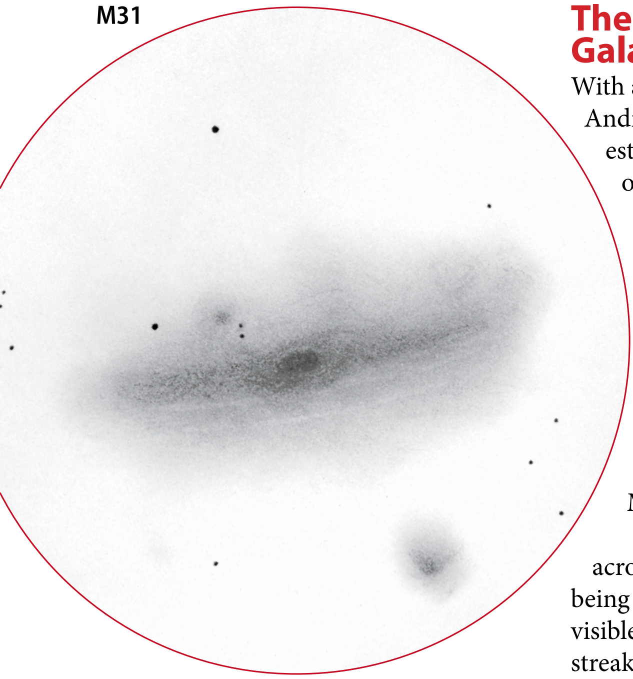
Astronomy's editor sketches two of his favorite objects. **by David J. Eicher**

The Andromeda Galaxy and NGC 1931

M31



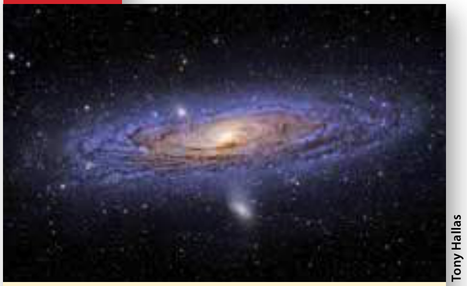
M31 sketched by David J. Eicher using a Celestron 8-inch f/10 SCT at 35x.

The Andromeda Galaxy (M31)

With a total magnitude of 3.4, the Andromeda Galaxy (M31) is the brightest spiral in the sky, visible without optical aid as a fuzzy patch spanning 3°. Easy to find about 1° west of Nu (ν) Andromedae, the galaxy is our "sister spiral" in the Local Group. It contains more than 300 billion stars whose combined mass may well exceed 1 trillion Suns. The galaxy lies 2.5 million light-years away; we could fit a dozen M31s end to end between it and the Milky Way.

M31's light is unevenly distributed across its surface, the brightest part being the galaxy's yellowish core — easily visible in binoculars as an elongated streak of light. A 6-inch telescope shows a large, extended outer halo of grayish nebulosity surrounding the core. An 8-inch scope on a dark night reveals two parallel dust lanes alongside the southern edge of the galaxy's hub, and a knotty patch of nebulosity near M31's southern tip that is NGC 206, a star cloud. The galaxy's two close satellites, M32 (close in) and NGC 205 (farther out) are also readily visible.

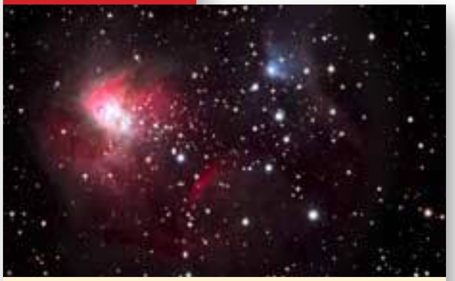
M31



Tony Hallas

Designations: M31, NGC 224
Position: 0h43m, 41°16' (2000.0)
Constellation: Andromeda
Magnitude: 3.4
Size: 190' by 60'
Distance: 2.5 million light-years

NGC 1931



Al and Andy Ferayorni/Adam Block/NOAO/AURA/NSF

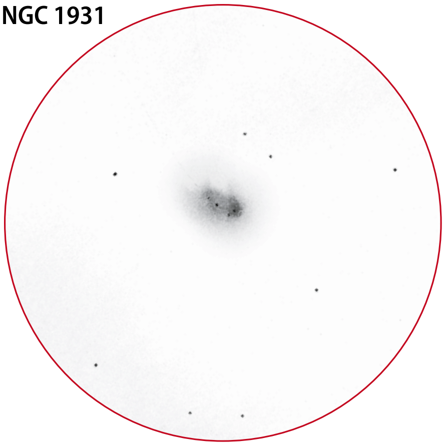
Designation: NGC 1931
Position: 5h31m, 34°15' (2000.0)
Constellation: Auriga
Magnitude: 10.1
Size: 3.2'
Distance: 10,000 light-years

NGC 1931

The constellation Auriga is famous for holding fabulous star clusters that gleam with dazzling light — M36, M37, and M38 in particular. But a lesser-known object in this constellation creates a challenge for many telescopes. NGC 1931 is a complex region of emission and reflection nebulosity surrounding young, hot stars. It glows, in part, because of gas excited by the stars like a fluorescent light and, in part, by simply reflecting the radiation of the stars toward our line of sight.

This region is one of the many small, dim objects scattered across the galactic plane. A 4-inch telescope shows the object as a bright knot of nebulosity without much form. An 8-inch scope reveals the nebula as a double-lobed patch of greenish light spanning some 3' with a few bright stars sprinkled across its face. A 16-inch scope more clearly shows the nebula's outline, which faintly resembles M76, the Little Dumbbell Nebula in Perseus.

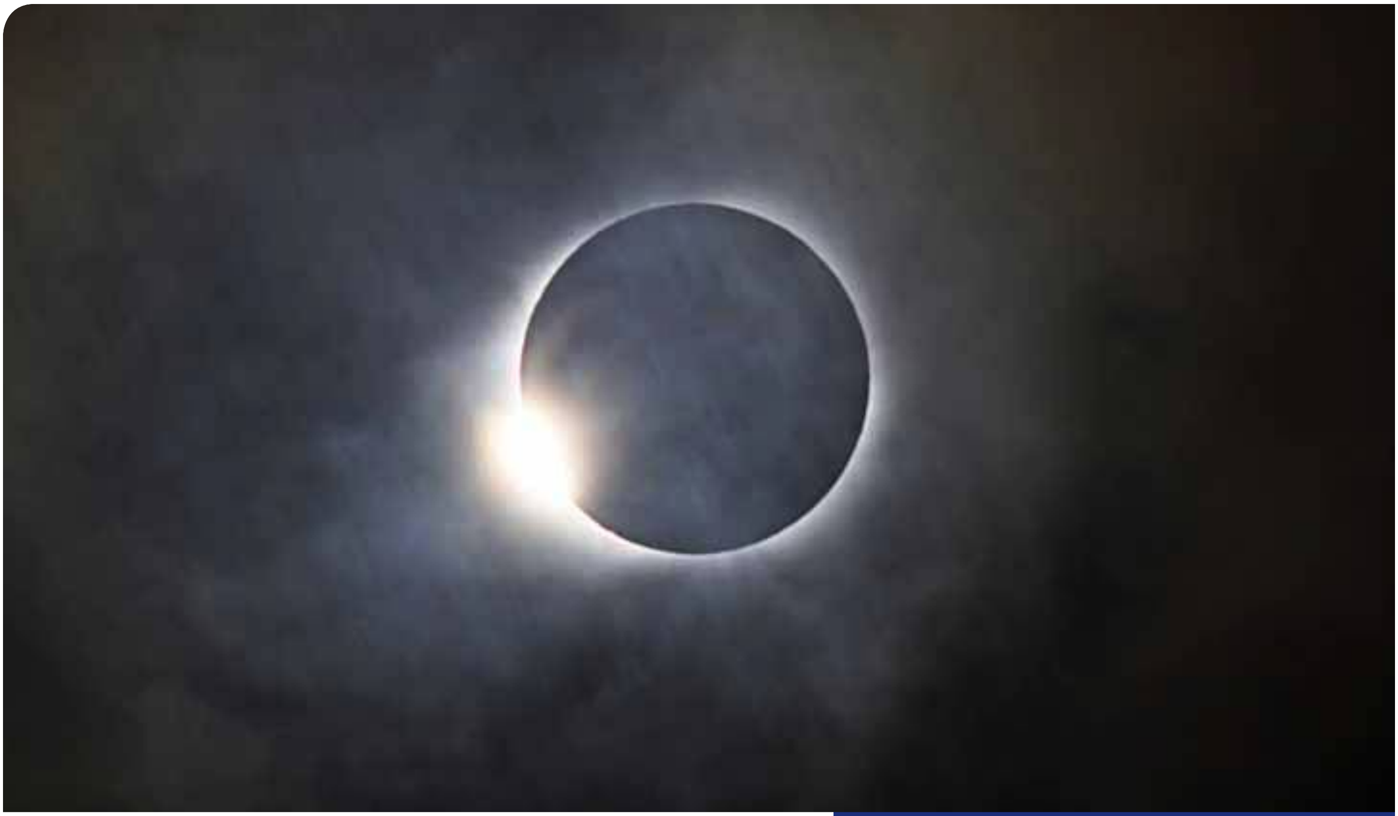
NGC 1931



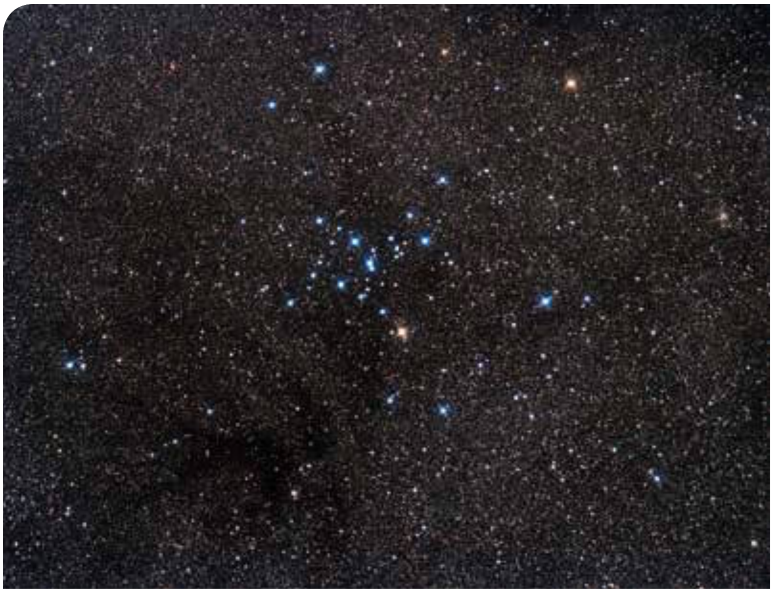
NGC 1931 sketched by David J. Eicher using a Celestron 8-inch f/10 SCT at 50x.

David J. Eicher *is the editor of* Astronomy. *He has observed and sketched deep-sky objects for 34 years.*

reader gallery



Shadow bands (3.2-inch Explore Scientific 80mm refractor at f/6.3, Canon EOS 5D Mark II DSLR, ISO 400, 1⁄800-second exposure, taken July 11, 2010, at 2:13:05 P.M. local time, from Easter Island) • Mike Reynolds, Jacksonville Beach, Florida

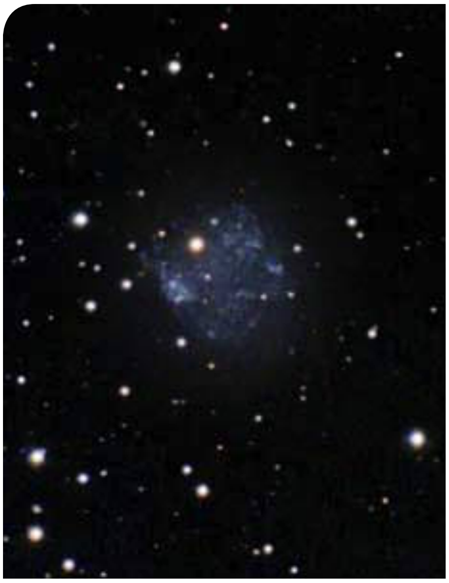


Ptolemy's Cluster (M7) in Scorpius lies just off the Scorpion's stinger. Its bright stars contrast nicely with the rich Milky Way. (8-inch Orion Newtonian Astrograph at f/4, Canon XTi DSLR, ISO 800, three 5-minute exposures) • Chris Schur, Payson, Arizona

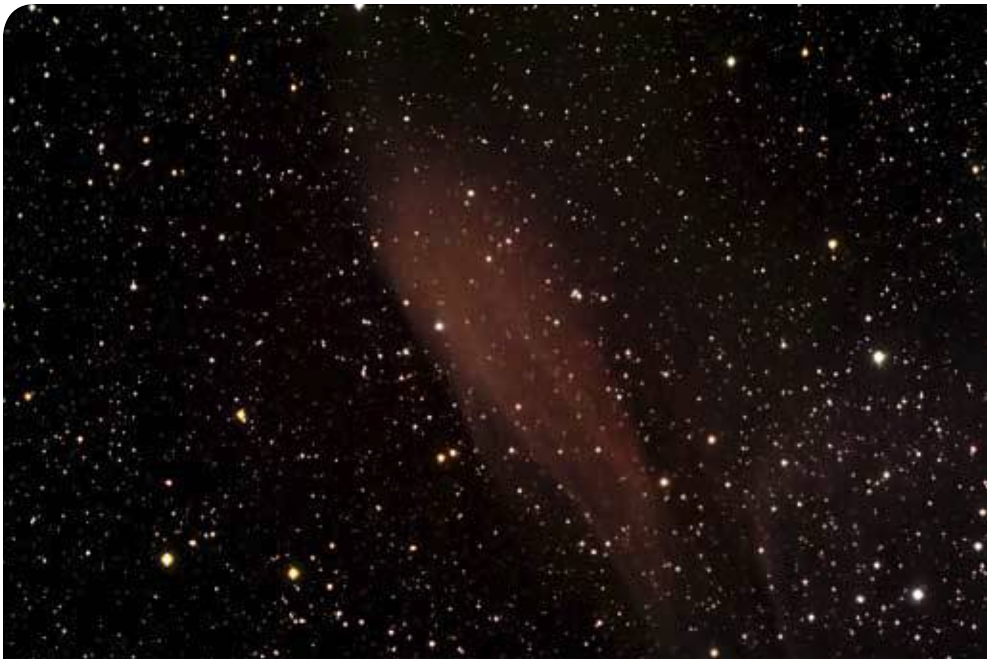
Shadow bands on clouds!

During the July 11, 2010, total solar eclipse, *Astronomy* Contributing Editor Mike Reynolds took many photographs from a site on Easter Island. This shot, however, stands out as a possible first: It appears to show shadow bands on the thin clouds that passed in front of the Sun and Moon at third contact.

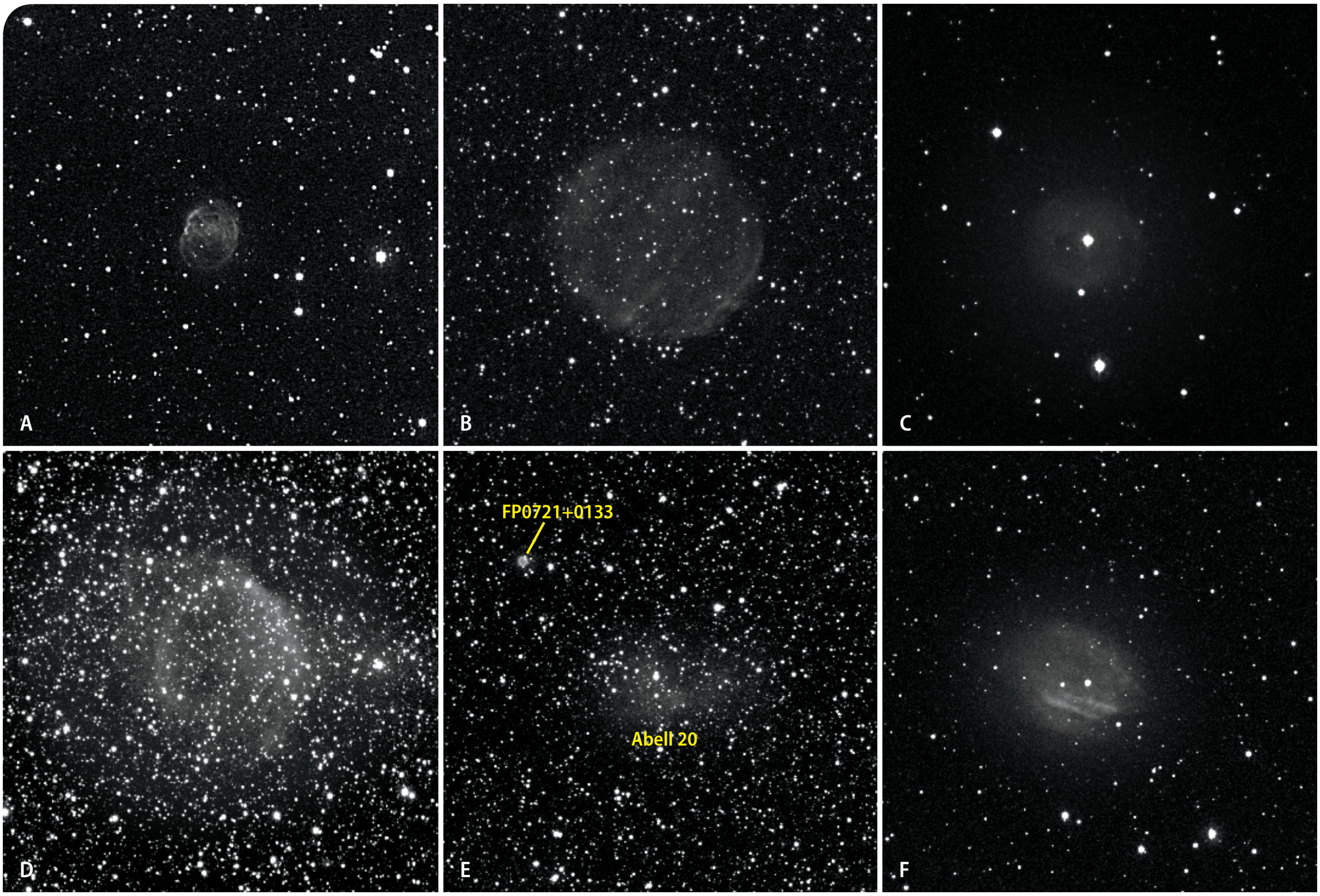
Shadow bands are parallel bright and dark lines. The bright ones are multiple images of the ever-so-thin solar disk just before totality begins and after it ends. The bands seem to undulate because our atmosphere is in motion. Eclipse-watchers have seen shadow bands appear infrequently on bright earthly surfaces, but not on clouds.



Sextans A is a dwarf irregular galaxy and one of the most distant members of the Local Group at 4.3 million light-years from Earth. (6-inch Explore Scientific David Levy Comet Hunter Maksutov-Newtonian telescope at f/4.8, Canon 350D DSLR, ISO 1600, twenty-seven 5-minute exposures) • Chuck Kimball, Julian, California



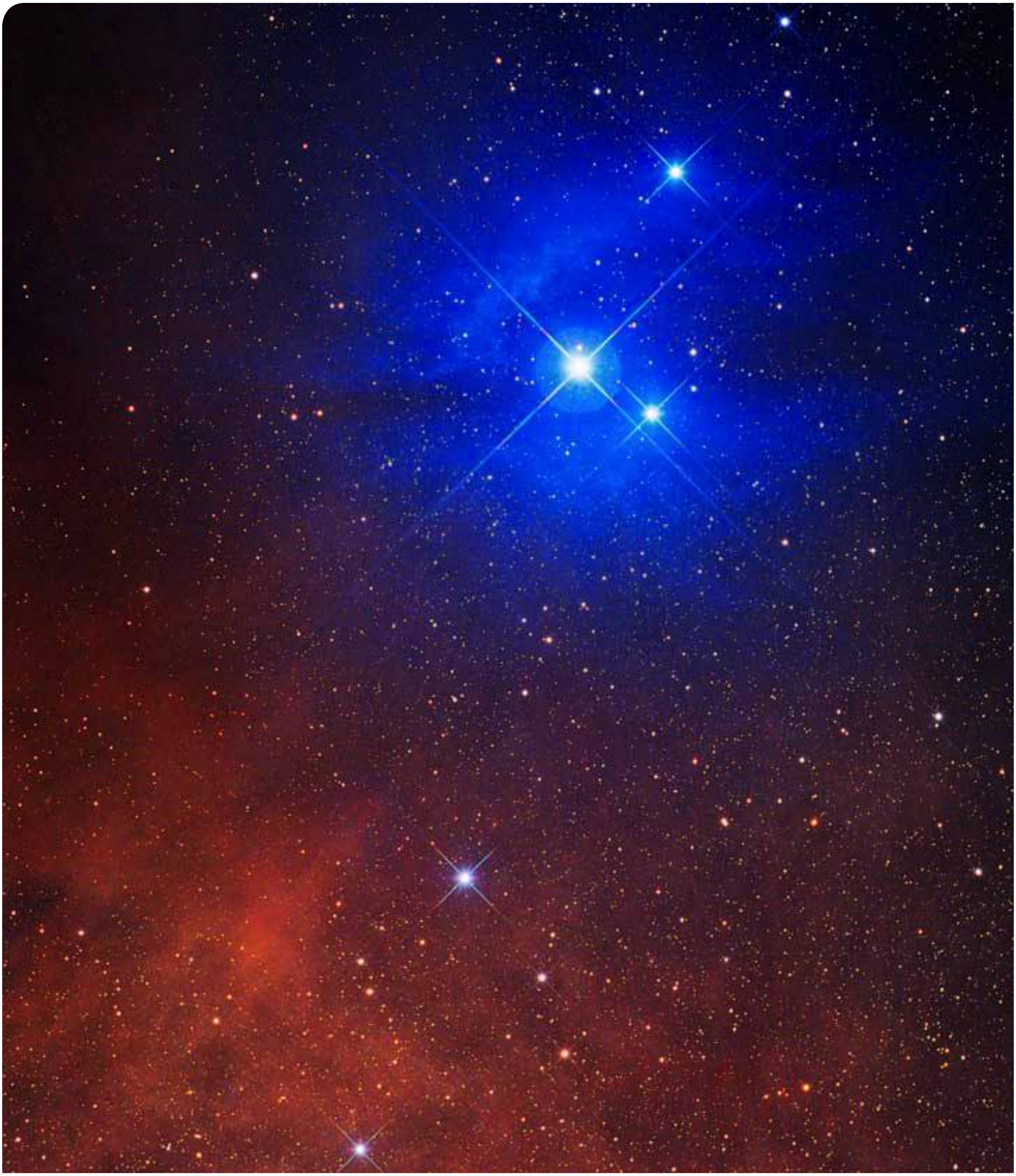
Sharpless 2–24 is an odd-looking molecular cloud in the southern part of Ophiuchus. At a distance of less than 750 light-years, Sh 2–24 ranks as one of the closest such objects to Earth. (8-inch Maksutov-Newtonian reflector at f/4, SBIG ST-10XME CCD camera, LRGB image with exposures of 2, 1, 1, and 1 hours, respectively) • Dean Salman, Tucson, Arizona



Examples of faint planetary nebulae observers classify as "obscure" include: A) Yerkes-McDonald 16 in Serpens; B) Purgathofer-Weinberger 1 in Lynx; C) Longmore-Tritton 5 in Coma Berenices; D) Weinberger-Dengle 1 in Orion; E) Abell 20 in Canis Minor (image also includes planetary nebula FP0721+0133); and F) Abell 35 in Hydra. (7.2-inch Takahashi Epsilon 180ED astrograph, ST-10XME CCD camera, Custom Scientific 4-nanometer Hydrogen-alpha filter, exposures ranging from 1.5 to 3 hours) • Rick Schrantz, Nicholasville, Kentucky

reader gallery

Send your images to: *Astronomy* Reader Gallery, P. O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, lens, ISO, filters, and exposures. Submit images by e-mail to readergallery@Astronomy.com.



Reflection nebula IC 4605 in Scorpius glows blue and surrounds the magnitude 4.8 star 22 Scorpii (the image's brightest star), which sits 1.3° north of Antares (Alpha [α] Scorpii). The orange emission nebula near the bottom is IC 4606. (12-inch ASA Astrograph at f/3.62, FLI ML8300 CCD camera, LRGB image with exposures of 40, 40, 30, and 30 minutes, respectively) **• Gerald Rhemann, Vienna, Austria**

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